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Contributed papers on any phase of malaria or related subjects should be submitted to the editor. If suitable papers contain tables, require illustrations, or will require more than six pages in the Journal for publication, acceptance will be contingent upon the willingness of the contributor to assume the extra cost entailed by special typesetting; manufacture of cuts or over-run, which amounts are to be paid directly to the printer. Orders for reprints should be placed with the printers, and are to be attached to the galley proof when it is returned to the editor.

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ON THE PARASITE DENSITY PREVAILING AT CERTAIN PERIODS IN VIVAX MALARIA INFECTIONS[1]

Mark F. Boyd
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The clinical activity exhibited by patients experiencing a malaria infection reflects the parasitemia occurring in the host. An appreciation of the characteristics of the parasitemia will give a better insight into the clinical manifestations of the infection. The present paper is an analysis of the parasite density prevailing during the course of naturally induced vivax malaria infections in 307 adult white patients, considering the pyrogenic level on (a) the day of onset (first temperature of 100° F.), (b) the first paroxysm attaining a temperature of 104° F., (c) the last day of clinical activity, and (d) the onset of the first three periods of reactivation.

In table I the parasite density (*i. e.* the parasites per cmm.) observed on the day of onset (first temperature of 100° F.) is compared with the duration of the interval between inoculation and onset. It will be noted that the microscopical examination of smears taken from 52 patients (16.9 per cent) failed to reveal parasites on that day, that in 188 (61.2 per cent) the parasites although detectable did not exceed 100 per cmm., and that in 22 (7.2 per cent) the density exceeded 1,000 per cmm. None of the onsets occurring within 14 days of inoculation exhibited coincident parasite densities exceeding 500 per cmm., while parasites were discernible at all onsets occurring more than 20 days from inoculations in densities of 10 or more per cmm. The data indicate that the parasite threshold

Table I. *Parasites per cmm. on day of onset (first 100° F.)*

		Negative	–10	10–100	101–500	501–1,000	1,001–5,000	5,001–10,000	10,001+	Total
Days from inoculation to onset	–13	41	53	67	11					172
	14–20	11	8	58	30	3	14	4	1	129
	21+			2	1		2	1		6
	Total	52	61	127	42	3	16	5	1	307

[1]The studies and observations on which this paper is based were conducted with the support and under the auspices of the International Health Division of The Rockefeller Foundation, in cooperation with the Florida State Board of Health and the Florida State Hospital.

necessary to promote clinical activity varies widely in different patients, but when the incubation period is prolonged, the level of the parasite density which excites the onset is likely to be higher.

The same data are considered from a slightly different standpoint in table II, which serves to emphasize the last point made in the previous paragraph. Here the density prevailing on the day of onset is considered according to the precedence of either of two events, *i.e.*, the beginning of the patent period and the day of onset. It will be noted that the parasite density increases as the interval between the end of the prepatent period and onset increases.

The days elapsing from inoculation to the first paroxysm attaining 104° F. are compared with the parasite density prevailing on that occasion in table III. It will be observed that nearly two thirds of the patients had parasite densities exceeding 1,000 per cmm. at the time of that event, and as in the case with the onset, the longer after inoculation this event was deferred, the higher the level of the coincident parasitemia.

The densities of parasites prevailing on the day of onset are compared with the densities prevailing on the day of the first ele-

TABLE II. *Parasites per cmm. on day of onset (first 100° F.)*

		Negative	— 10	10— 100	101— 500	501— 1,000	1,001— 5,000	5,001— 10.000	10,001 +	Out	Total
Days incubation shorter than prepatent	4	1									1
	3	2									2
	2	6									6
	1	28	3								31
	Same		43	4							47
Days incubation longer than prepatent	1	13*	15	50	5						83
	2	2*		45	11						58
	3			20	16	1	3				40
	4			5	6	1	6	1			19
	5			2	4	1	3		1		11
	6						2	2			4
	7						2	1			3
	Out									2	2
	Total	52	61	126	42	3	16	4	1	2	307

*Parasites previously seen but smears negative on indicated day.

Table III. *Parasites per cmm. on day of first temperature of 104° F.*

Days from inoculation to first temperature 104° F.	Negative	— 10	10— 100	101— 500	501— 1,000	1,001— 5,000	5,000— 10,000	+ 10,001	Total
Not reached	*								13
—13		1	16	9		1			27
14—20		4	20	31	24	99	46	19	243
21—27			1	1		10	2	8	22
28+						1	1		2
Total		5	37	41	24	111	49	27	307

Table IV. *Parasites per cmm. on day of first temperature of 104° F.*

Parasites per cmm. on day of onset (First 100° F.)	Termination spontaneous									Termination induced								
	Not reached	–10	10–100	101–500	501–1,000	1,001–5,000	5,001–10,000	10,001 +	Total	Not reached	–10	10–100	101–500	501–1,000	1,001–5,000	5,001–10,000	10,001 +.	Total
Negative			4	8	2	14	8	2	38	2	1	4	5	1	1			14
–10		1	11	5	4	16	5	3	45	1		1	2	3	6	2	1	16
10–100	4	3	15	14	11	35	14	5	101			2	4	2	12	4	2	26
101–500	3			2	1	19	6	6	37				1		2	2		5
501–1,000						1	1		2							1		1
1,001–5,000	2					4	2	4	12	1					1		2	4
5,001–10,000							4	1	5									
10,001 +																	1	1
Total	9	4	30	29	18	89	40	21	240	4	1	7	12	6	22	9	6	67

Table V. *Parasites per cmm. on last day of clinical activity.*

Parasites per cmm. on day of first 100° F.	Termination spontaneous: Not observed	–10	10–100	101–500	501–1,000	1,001–5,000	5,001–10,000	10,001+	Total	Termination induced: Not observed	–10	10–100	101–500	501–1,000	1,001–5,000	5,001–10,000	10,001+	Total
Negative				2	1	27	8		38			1	2	1	6	1	3	14
–10	1			3	8	28	4	1	45	1			1	4	5	1	4	16
10–100			1	7	14	66	10	3	101	1			2		13	4	6	26
101–500			2	1	4	19	7	4	37						3	1	1	5
501–1,000				1			1		2					1				1
1,001–5,000				2		7	3		12						1	1	2	4
5,001–10,000						3	1	1	5									
10,001+															1			1
Total	1		3	16	27	150	34	9	240	2		1	5	6	29	8	16	67

Table VI. *Parasites per cmm. on last day of clinical activity.*

Duration continuous clinical activity until termination or remission 5 or more days	Termination spontaneous									Termination induced								
	Not observed	– 10	10– 100	101– 500	501– 1,000	1,001– 5,000	5,000– 10,000	10,001 +	Total	Not observed	– 10	10– 100	101– 500	501– 1,000	1,001– 5,000	5,000– 10,000	10,001 +	Total
Days: -7			1	3		12	3	1	20			1	1		3			5
7-13			2	7	8	27	10	2	56				1	1	3		3	8
14-27	1			2	7	42	13	3	68				2	2	13	4	7	28
28-41				4	7	41	3	3	58	2			1	3	9	2	5	22
42+					5	28	5		38						1	2	1	4
Total	1		3	16	27	150	34	9	240	2		1	5	6	29	8	16	67

vation to 104° F. in table IV, further distinguishing whether the subsequent attacks terminated spontaneously or were therapeutically interrupted. There is no indication that the parasite levels prevailing at the onsets of these patients whose attacks were subsequently interrupted tend to be lower, while both groups exhibit a similar trend insofar as it relates to the density prevailing on the first temperature of 104° F.

The parasite density prevailing on the first day of clinical activity (onset), is compared with that of the last in table V, distinguishing further the manner of termination of the attack. As may be expected, the parasite densities prevailing on the last day of the interrupted attacks are more frequently higher than those noted when termination was spontaneous. Whereas most attacks have been initiated by parasite densities between 10 and 100 per cmm., clinical activity usually terminates spontaneously with a density of from 1,001 to 5,000 parasites per cmm. This indicates in general a progressive rise in the pyrogenic level during the evolution of the attack. Nevertheless in some patients the terminal density has been lower than that required to initiate the attack.

The duration of the initial period of continuous clinical activity is compared with the parasite density prevailing on its last day in table VI, further distinguishing the manner of termination of the attack. It does not appear that the parasite density prevailing at the close of either spontaneously terminating or interrupted attacks has varied significantly with the duration of the attack.

The parasite densities prevailing at the onset of the primary attacks are compared with those observed at the onset of recrudescenses and relapses in table VII. While in general the threshold density at a recrudescence or relapse has been materially higher than at the original onset, there are instances where there has been no substantial change in parasite density, and even a few instances where clinical reactivation has occurred at densities lower than those prevailing at the onset of the primary attack.

In table VIII the duration of the first three remissions is compared with the parasite density observed at the onset of the recrudescences or relapses by which the remissions were terminated, further distinguishing whether the remissions arose spontaneously or were induced. Although the spontaneous remissions tend to be of shorter duration than the induced remissions, any noteworthy difference in parasite thresholds is inapparent, nor do these levels tend to become progressively higher in subsequent reactivation.

Table VII. *Parasites per cmm. on day of onset of recrudescence or relapse.*

Parasites per cmm. on day of onset (First 100° F.)	Termination primary spontaneous								Termination primary induced							
	10-100	101-500	501-1,000	1,001-5,000	5,001-10,000	10,001 +	Undetermined	Total	10-100	101-500	501-1,000	1,001-5,000	5,001-10,000	10,001 +	Undetermined	Total
Negative		2	2	12	2	1		19	1			3				4
–10		4	1	11	1			17		1	3	1	3			8
10–100	1	4	5	13	3		2	28		2	1	5	2			10
101–500		1		7			1	9				2	1			3
501–1,000				1	1			2								
1,001–5,000				3		1		4				2	2			4
5,001–10,000			1	1	2			4								
10,001 +											1					1
Total	1	11	9	48	9	2	3	83	1	3	5	13	8			30

Table VIII. *Parasites per cmm. on day of onset of recrudescences and relapses.*

Duration Remission	Days	Termination previous activity spontaneous								Termination previous activity induced							
		10-100	101-500	501-1,000	1,001-5,000	5,001-10,000	10,001 +	Undetermined	Total	10-100	101-500	501-1,000	1,001-5,000	5,001-10,000	10,001 +	Undetermined	Total
First	-7		3	2	23	4			32				3				3
	7-20	1	6	7	23	4	1	2	44		3	4	5	4			16
	21-34		2		2	1	1	1	7			1	1	1			3
	35-62									1							1
	63+												4	3			7
	Total	1	11	9	48	9	2	3	83	1	3	5	13	8			30
Second	-7			3	5	1			9								
	7-20		1	6	13	3	1		24			3				1	4
	21-34		1					1	2			1				1	2
	35-62														1		1
	63+												1	1			2
	Total		2	9	18	4	1	1	35			4	1	1	1	2	9
Third	-7				1				1								
	7-20	1	1		4		1		7								
	21-34				1				1								
	35-62																
	63+				1				1								
	Total	1	1		7		1		10								0

Summary

The pyrogenic density of parasites varies at different periods in the evolution of vivax malaria infections. Most onsets occur with densities of less than 100 parasites per cmm., although several have been deferred until appreciably higher densities were attained. The latter individuals had likely previously experienced a vivax infection. The densities necessary to initiate the first paroxysm attaining a temperature of 104° F. are in general materially higher than those required to initiate the onset, and tend to increase in level with the time elapsing from inoculation. The attacks which later required therapeutic interference do not exhibit any greater tendency to present their onset and their subsequent initial paroxysm of 104° F. at lower pyrogenic levels. The last clinical activity observed in spontaneously terminating attacks usually occurs at a pyrogenic level many times higher than that which initiated the attack. Since indications for therapeutic interference are varied and arise at different periods, the parasite densities occurring at the last paroxysm before interruption are similarly variable although not materially different from those in the spontaneously terminating attacks. When clinical reactivation occurs, it is usually at pyrogenic levels materially higher than those prevailing at the onset, but these levels do not appear to become progressively higher with further and multiple reactivations.

THE RELATION OF THE INTERSECTION LINE TO THE PRODUCTION OF *ANOPHELES QUADRIMACULATUS*

By L. E. Rozeboom and A. D. Hess*

It has long been known that the production of *Anopheles quadrimaculatus* is almost entirely limited to waters containing vegetation and flotage. This implies that some ecological factor associated with the presence of such vegetation and flotage determines the capacity of any particular situation to produce this mosquito. If this factor could be defined and measured, it would provide a more direct and precise means for determining the production potentials of the various types of environment in which *A. quadrimaculatus* normally breeds. Hess and Hall (1943A) have described such a factor and have termed it the "intersection line." They define the intersection line as "the line of intersection between three interfaces, water-air, water-plant, and plant-air." For use in making comparisons, they define the term "intersection value" as "the number of meters of intersection line per square meter of water surface."

In the preliminary studies which the above authors made in American lotus, *Nelumbo lutea*, they found a positive correlation between the amount* of intersection line and the number of *Anopheles* larvae per unit of water surface area. They expressed the opinion that a similar correlation might exist in other types of littoral vegetation in which malaria mosquitoes breed. If this theory could be confirmed, it would aid greatly in understanding and intelligently applying water level management and other naturalistic measures used by the Tennessee Valley Authority to control the production of *A. quadrimaculatus* on its impounded waters. The present studies were therefore initiated to determine the relation of intersection line to the production of *A. quadrimaculatus* in representative types of aquatic and semi-aquatic vegetation occurring in the reservoirs of the Tennessee Valley. The data presented were collected during June and July 1943 in the North Alabama section of the Tennessee Valley.

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*From the Department of Parasitology of the Johns Hopkins School of Hygiene and Public Health, and the Health and Safety Department of the Tennessee Valley Authority.

*These authors used the term "amount" to refer to the linear extent of the intersection line, and for convenience the term will be used in a similar way in this paper.

The authors gratefully acknowledge the assistance of Dr. J. T. Self, Dr. R. L. Metcalf, Mr. J. N. Belkin, and Mr. George Keener in collecting the field data.

METHODS

Selection of Plants and Plots

An attempt was made to select species of plants representing each of the seven types of vegetation given by Hess and Hall (1943B) in their classification of plants in relation to the production of *A. quadrimaculatus;* however, limited time and unfavorable water elevations made it possible to sample only five of these seven types as follows:

1. Submerged Type — *Chara sp.*
2. Grass Type — *Paspalum distichum, Homalocenchrus oryzoides, Panicum agrostoides,* and *Eleocharis smallii.*
3. Leafy-Emergent Type — *Saururus cernuus*
4. Naked-Emergent Type — *Eleocharis quadrangulata*
5. Floating-Leaved Type — *Nelumbo lutea*
6. Floating Mat Type — None sampled
7. Carpet Type — None sampled

Sampling plots were chosen as nearly as possible where there was a pure stand of the species being investigated, and where breeding of *A. quadrimaculatus* was relatively heavy. Most of the samples were collected in the Cave Springs and Black's Branch areas of Wheeler Reservoir which are within the Wheeler National Wildlife Refuge and are not subjected to the normal larvicidal program which is applied to other areas. The series of samples from *Chara* were collected in the Annie Pond region west of Florence, Alabama, the only location where this plant was found in sufficient abundance for sampling.

Sampling Methods

A square wooden frame one-half meter on a side and about eight inches deep was used as the standard sampler. This was placed among the plants, and the collector, standing above it, looked down and estimated the percentage of the water surface that was covered by the vegetation and the amount of intersection line within the area enclosed by the frame. Except for lotus, the amount of intersection line in each sample was recorded as high, medium, low, or zero, the latter group including some samples which contained a small amount of intersection line. Although this method did not provide an absolute measure of intersection line, it was found to be

the most convenient method for determining relative amounts and proved to be fully satisfactory for general correlation studies. In the case of lotus, absolute measurements of the intersection line were obtained in order to provide a check against the relative measurements made in the other plant species. A flexible steel tape was used to measure the leaf diameters or, when only parts of leaves were included within the frame, the leaf margin itself. It was desired to make these measurements in the metric system, but the only steel tapes available were calibrated in inches. Because the heavy sampling frame would cause the lotus leaves to submerge, the measurements were made before placing the frame, the area being enclosed with four light sticks, each one-half meter in length. After the measurements had been made, the sampling frame was placed over the same area, and the egg and larva collections were made. These collections were made by skimming the surface with a white enameled dipper or cup. Larvae and pupae were counted and discarded, but the eggs were transferred to vials containing strips of paper towel and taken to the laboratory for positive identification under a microscope; thus seeds and bits of debris which had been mistaken for eggs were eliminated from the results. It is believed that this method furnished a fairly reliable count of eggs and larvae; although the egg counts may possibly not have been as accurate as the larva counts, the errors were of similar magnitude under all conditions and should therefore not affect the correlations with intersection line.

Statistical Techniques

The statistical techniques used in this paper are those outlined by Paterson (1939) and involve mainly the calculation of standard deviations and standard errors for use in making tests of significance. In all cases where a mean is followed by a $\pm$ figure, this figure is the standard error (standard deviation of the mean) as defined by the above author. Differences with probabilities greater than 0.05 are termed "nonsignificant," those between 0.05 and 0.01 "significant," and those less than 0.01 "highly significant."

Calculations involving multiplication, division, percentages, ratios, squares, and square roots were made on a 21-inch slide rule reading to three significant figures.

Unweighted means were used in figuring egg and larva averages for individual plant species or for combinations of species. The use of unweighted means was obviously desirable in this case because of the varying number of samples collected within the different groups and different species.

RESULTS AND DISCUSSION

In Table I is given the number of samples and the mean number of eggs and larvae in each intersection line group for the eight species of plants in which collections were made. The same data are presented graphically in Figure 1.

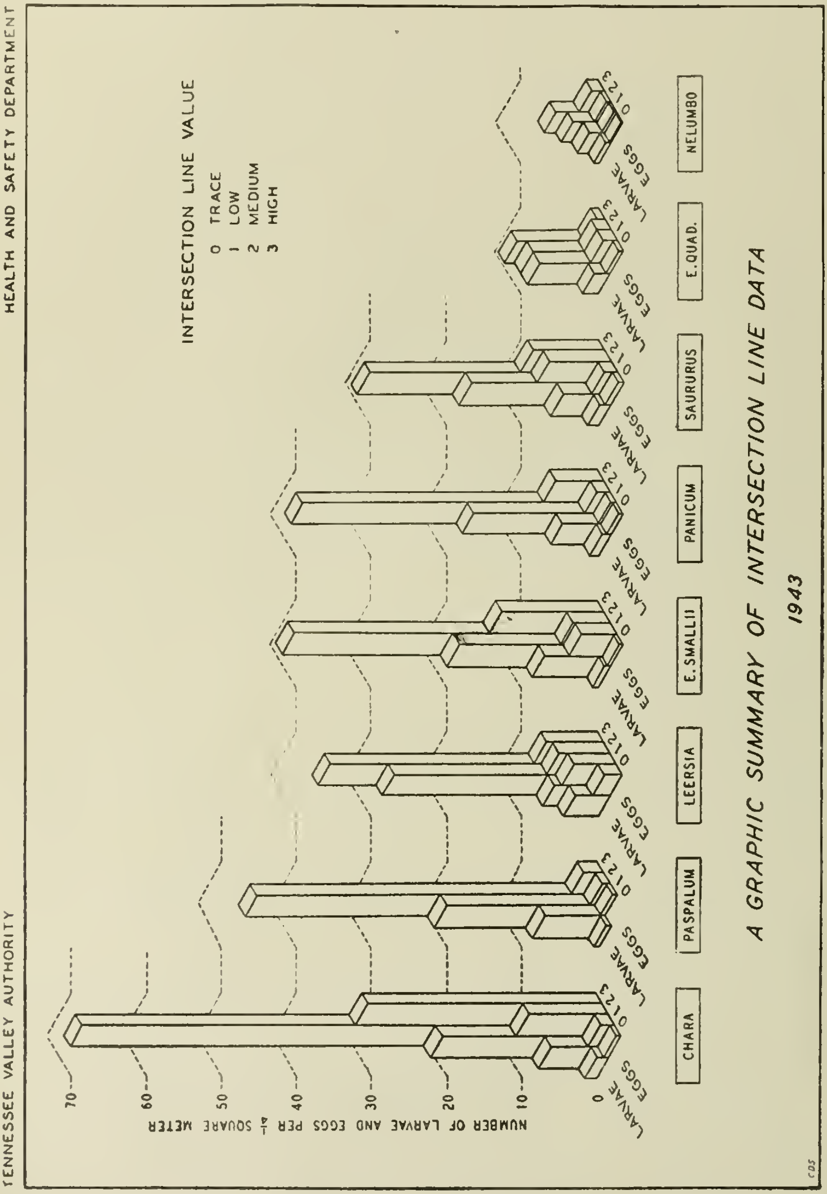

Fig. 1—*A Graphic Summary of Intersection Line Data, 1943.*

An examination of these data will show that for both eggs and larvae there was a positive correlation between population densities and the amount of intersection line in 23 out of 24 comparisons in the eight plant species investigated. Increased egg counts in progressive intersection line groups were significant or highly significant in 12 of the 24 comparisons, and increases in larvae were highly significant 16 times and significant twice in the 24 comparisons.

TABLE I. A Summary of Intersection Line Data From 805 Samples Collected in Eight Species of Plants During the Summer of 1943.

PLANT SPECIES		Mean Numbers of Eggs and Larvae per ¼ Sq. Meter INTERSECTION LINE GROUPS				
		0	Low	Medium	High	Av.*
Chara sp.	No. Samples	15	12	17	17	
	Eggs	0.6 ± 0.3	1.8 ± 0.9	10.7 ± 2.7	31.2 ± 4.6	11.1
	Larvae	1.7 ± 0.9	7.3 ± 1.1	20.5 ± 4.1	67.4 ± 6.7	24.2
Paspalum distichum	No. Samples	8	21	22	12	
	Eggs	0.0 ± 0.0	0.4 ± 0.2	1.0 ± 0.2	2.4 ± 0.7	1.0
	Larvae	0.4 ± 0.2	8.3 ± 2.2	20.4 ± 2.3	44.7 ± 3.9	18.5
Homalocenchrus oryzoides	No. Samples	9	14	8	8	
	Eggs	2.6 ± 0.9	5.9 ± 3.2	7.0 ± 2.5	7.6 ± 2.3	5.8
	Larvae	4.9 ± 1.8	6.9 ± 1.9	27.3 ± 10.0	34.5 ± 12.0	18.4
Eleocharis smallii	No. Samples	24	24	23	19	
	Eggs	0.4 ± 0.1	4.8 ± 1.9	5.0 ± 1.0	13.4 ± 3.2	5.9
	Larvae	0.6 ± 0.3	7.6 ± 1.5	18.8 ± 2.6	39.7 ± 5.9	16.7
Panicum agrostoides	No. Samples	16	21	31	16	
	Eggs	0.5 ± 0.2	0.7 ± 0.2	1.8 ± 0.3	6.2 ± 1.2	2.3
	Larvae	1.1 ± 0.3	5.8 ± 0.7	16.4 ± 1.9	38.3 ± 5.8	15.4
Saururus cernuus	No. Samples	14	25	27	26	
	Eggs	0.6 ± 0.3	1.7 ± 0.9	8.2 ± 1.6	9.5 ± 1.3	5.0
	Larvae	1.6 ± 0.9	5.6 ± 1.8	16.9 ± 2.2	29.5 ± 4.0	13.4
Eleocharis quadrangulata	No. Samples	7	17	22	22	
	Eggs	0.4 ± 0.1	1.6 ± 0.4	1.7 ± 0.4	0.8 ± 0.3	1.1
	Larvae	2.0 ± 0.8	8.8 ± 1.2	8.8 ± 1.7	9.7 ± 1.9	7.3
Nelumbo lutea	No. Samples	37	37	188	46	
	Eggs	0.2 ± 0.1	0.4 ± 0.1	0.6 ± 0.1	1.5 ± 0.4	0.7
	Larvae	0.9 ± 0.2	2.4 ± 0.5	3.4 ± 0.2	4.8 ± 0.6	2.9
Total Numbers of Samples		130	171	338	166	805
Averages*	Eggs	0.66	2.2	4.5	9.1	
	Larvae	1.65	6.6	16.6	33.6	
Ratio of Eggs to Larvae		0.40	0.33	0.27	0.27	

*Unweighted.

The smaller number of significant differences in the egg counts was undoubtedly due to the lower population densities for eggs which would make it necessary to collect a larger number of samples in order to measure significant differences.

It will be noted that the only plant species in which there was not a positive correlation between both egg and larva densities and the amount of intersection line for all intersection line groups was the square-stemmed spike rush, *Eleocharis quadrangulata.* This species is a naked-stemmed emergent, and its maximum intersection value therefore occurs in a dense stand where the vertical stems closely approximate each other. As illustrated in Figure I, the egg counts showed a significant increase from the zero to the low intersection line group, showed a slight but nonsignificant increase from the low to the medium, and showed a sharp decrease from the medium to the high group, the decrease closely approaching the level of significance with a probability of 0.07. This suggests that dense stands of vertical emergent stems present a mechanical barrier to oviposition which offsets the effect of the increased intersection value. Rozeboom and Belkin (1942) reached a similar conclusion from actual oviposition tests with *A. quadrimaculatus* which they conducted in various types of vegetation during the summer of 1942. Likewise Russell and Rao (1942) found that mechanical obstruction produced by vertical rods or stems repelled ovipositing females of *A. culicifacies.*

Since it is apparent that, with the above exception, environmental situations with the highest intersection values present the greatest attraction for ovipositing females of *A. quadrimaculatus,* the question arises as to whether the higher larva densities in such situations are entirely due to increased oviposition or whether decreased larva mortality also plays a part. A key to this question is given in the figures at the bottom of Table I, which give the mean ratio of eggs to larvae for each of the intersection line groups. It will be noted that the ratios decrease in the progressive intersection line groups although they are the same for the medium and high groups. This increase in the relative abundance of larvae in the higher intersection line groups indicates a decrease in larval mortality, probably due to the increased protection from natural enemies such as *Gambusia.* Thus the correlation between larva densities and intersection values would appear to be due to the combined effect of increased oviposition and decreased larval mortality. This information adds weight to the statement by Hess and Hall (1943) that the intersection line provides *A. quadrimaculatus* with the three fundamental requirements for successful propagation, namely, "food, shel-

ter, and facilities for reproduction."

In a very interesting paper, Renn (1943) has discussed the relation of positive and negative menisci at the intersection line to the presence of *Anopheles* larvae, and has shown how the intersection line produced by emergent vegetation actually "selects" the larvae through the action of simple surface tension forces. Thus it appears from the combination of information available that the high positive correlation between larva densities and intersection values is merely the logical outcome of natural selection acting upon the species.

The data on actual measurements of intersection line and egg and larva counts in lotus are presented in Table II and graphically

TABLE II. The Relation of Plant Cover and Intersection Line to the Densities of Eggs and Larvae of *Anopheles quadrimaculatus* in Lotus. Results Based on 252, ¼ Square Meter Samples Collected During the Summer of 1943.

	Plant Cover Classes				
	0-20%	21-40%	41-60%	61-80%	81-100%
Mean % Cover	2.2	28.9	51.3	71.3	93.6
Mean Amount Int. Line in Inches	4.1	45.8	70.9	84.9	28.8
Mean No. of Eggs Per Sample	0.1	0.3	0.6	0.96	0.26
Mean No. of Larvae Per Sample	0.7	2.1	3.4	4.0	1.1
Number of ¼M. Samples	27	35	60	107	23

summarized in Figure II. For this study, colonies of lotus were chosen in which all leaves were of the floating type. The data are in close agreement with those obtained by relative estimates of intersection line in other plant species, and thus confirm the validity of the methods used and the results obtained. As shown in Figure II, the data indicate a very close correlation between egg and larva densities and intersection values; also, the relation between cover and intersection line closely approaches that for a hypothetical situation in which all the leaves are the same size, perfectly round, and the maximum intersection value is reached when all leaves are tangent in check rows. The correlation between larva densities and intersection values is in close agreement with the results given by Hess and Hall (1943A) from their studies in lotus. Their results also agree with the present study in that the maximum intersection value (See definitions on Page 1) for lotus was found to be slightly over eight. They found this maximum value with plant covers of about 50 per cent, while in the present study it was around 70 per cent. This is probably due to the fact that their data were collected from a lotus colony having mixed sizes of leaves while the present studies

were made where the leaves were of a fairly uniform size.

Since there is a consistent correlation between egg and larva densities and intersection values within the individual plant species, it would be expected that the relative production potentials of differ-

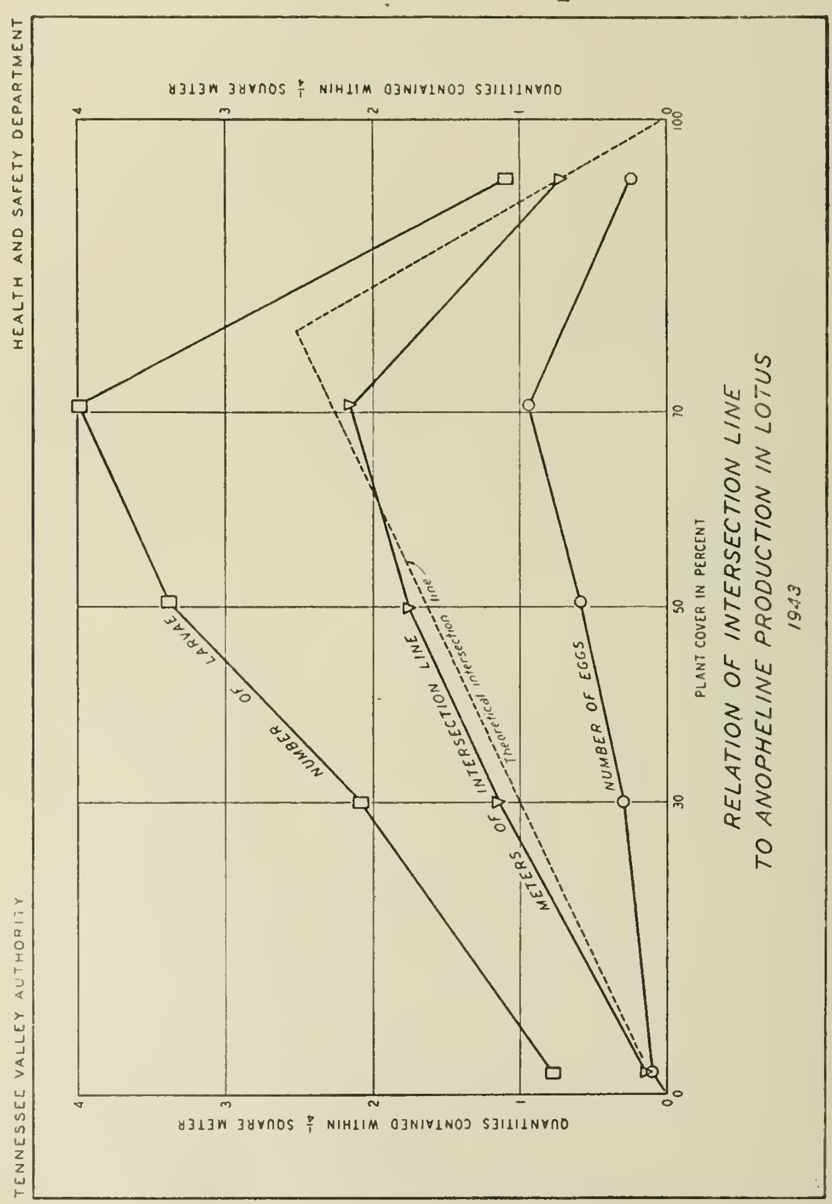

Fig. II—*Relation of Intersection Line to Anopheline Production in Lotus, 1943.*

ent species would be in accordance with their relative intersection values; thus the species which produced the greatest amount of intersection line per unit of water surface area would also produce the greatest numbers of *A. quadrimaculatus,* other factors remaining equal. While it is extremely difficult to make absolute measurements of intersection line in most plants, the differences in the intersection values of the different types are of sufficient magnitude that they may be placed in their relative order merely by visual comparison. This has been done in Table III for the five types included in

TABLE *III.* Intersection Line Data of Table I Summarized by Plant Types; Which are Listed in Decreasing Order According to Estimated Production of Intersection Line.

PLANT TYPES		Numbers of Eggs and Larvae Per ¼ Square Meter Intersection Line Groups				
		O	Low	Medium	High	Mean
Submerged						
	Eggs	0.6	1.8	10.7	31.2	11.1
	Larvae	1.7	7.3	20.5	67.4	24.2
Grass-Like						
	Eggs	0.9	3.0	3.7	7.4	3.8
	Larvae	1.8	7.2	20.7	39.3	17.3
Leafy-Emergent						
	Eggs	0.6	1.7	8.2	9.5	5.0
	Larvae	1.6	5.6	16.9	29.5	13.4
Naked-Emergent						
	Eggs	0.4	1.6	1.7	0.8	1.1
	Larvae	2.0	8.8	8.8	9.7	7.3
Floating-Leaved						
	Eggs	0.2	0.4	0.6	1.5	0.7
	Larvae	0.9	2.4	3.4	4.8	2.9

this study, the four grass-like species being averaged together. It will be noted from the table that types with higher intersection values invariably produced greater numbers of larvae. A similar correlation holds for the egg counts in all types except the grass-like. This one discrepancy in the egg correlations reflects the difficulty in selecting comparable plots for making comparisons between different plant species, particularly when the sampling can not be done in all species on the same day. The egg counts for *Paspalum* and *Panicum* were unusually low as compared with data from the previous season (Rozeboom and Belkin, 1942), and the egg counts for the leafy-emergent (*Saururus*) were unusually high. Also the counts in *Saururus* were taken during especially favorable water elevations and probably during a more favorable oviposition period since a large portion of the grass samples were collected over three weeks earlier than the *Saururus* samples. In general, however, the data confirm the theory that, other factors remaining equal, the relative produc-

tion of *A. quadrimaculatus* in different species of plants will be in proportion to their relative intersection values.

As has been pointed out by Hess and Hall (1943A), the intersection values for individual plant species are closely related to prevailing water elevations. In a manuscript which is soon to be submitted for publication, these same authors (1943B) have discussed this relationship in detail and have pointed out its importance in water level management for malaria control. The subject will therefore not be discussed further in the present paper.

SUMMARY AND CONCLUSIONS

Studies to determine the relation of the intersection line to the production of *Anopheles quadrimaculatus* were made in eight species of littoral plants representing the following five ecological types: 1. Submerged; 2. Grass-Like; 3. Leafy-Emergent; 4. Naked-Emergent; and, 5. Floating-Leaved. The studies were made during June and July 1943 in the North Alabama section of the Tennessee River Valley, and involved the collection of 805 one-fourth square meter samples from reservoirs and ponded areas.

From the results obtained, it is concluded that in individual plant species there is a close positive correlation between the production of *A. quadrimaculatus* and the amount of intersection line per unit of water surface area; and that the increased production which accompanies high intersection values is probably due to the combined effect of increased oviposition and decreased larval mortality. The only exception to the above correlation occurred in dense stands of the naked-emergent type (*Eleocharis quadrangulata*) which appeared to present a mechanical barrier to oviposition.

The results also indicate that, with the above exception, the relative production of *A. quadrimaculatus* in different species of plants is in direct proportion to their relative intersection values, other factors remaining equal.

It is believed that this confirmation of the intersection line theory will be a real help in understanding and intelligently applying water level management and other naturalistic measures which the Tennessee Valley Authority uses for the control of malaria mosquitoes on its impounded waters.

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WATER LEVEL MANAGEMENT FOR MALARIA CONTROL ON IMPOUNDED WATERS

By A. D. Hess* and C. C. Kiker*

INTRODUCTION

Water level fluctuation for malaria control has been used on impounded waters in the Southeastern United States for over a quarter of a century. Stromquist (1935) and Hinman (1938) have presented a resume of the development of this measure and have discussed its early application on the reservoirs of the Tennessee Valley Authority. Later, Hinman (1941) has given a general discussion of the management of water for malaria control and has summarized the experiences with water level fluctuation on the Tennessee Valley reservoirs through the season of 1940. It is the purpose of the present paper to discuss the water level management practices in current use on the impoundments of the Tennessee Valley Authority, with particular reference to new developments which have taken place since 1940.

Normal seasonal changes in water elevations have repeatedly been observed to play an important part in controlling the production of *Anopheles quadrimaculatus* in limesink ponds and similar natural bodies of water (Hinman, 1938; Taylor, 1940). For this reason, the authors of the present paper classify water level management as a naturalistic control measure, considering it a deliberate extension and intensification of a form of natural control.

Water level management for malaria control is effective through the creation and maintenance of clean water conditions which are unsuitable for the production of malaria mosquitoes; thus, it is merely a practical application of the well-known maxim that a clean water surface will not produce *Anopheles quadrimaculatus.*

The recently established correlation between *Anopheles quadrimaculatus* production and the amount of intersection line* produced by littoral vegetation (Hess and Hall, 1943; Rozeboom and Hess, 1943) provides a means for the precise measurement of anopheline production potentials and thus advances the knowledge of the relationship of this production to physical conditions of the water

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*This is the intersection of air, plant, and water.

surface. The knowledge of this relationship provides for a better understanding and more intelligent application of water level management for malaria control. Thus, it would appear that the effectiveness of a schedule of water level management in controlling anopheline production is mainly dependent upon the extent to which it reduces the amount of intersection line in the problem areas at appropriate intervals during the mosquito breeding season. Since plants or plant remains are almost entirely responsible for the creation of intersection line in natural breeding areas of *Anopheles quadrimaculatus,* it follows that a knowledge of the water relationships of littoral plants is of paramount importance in applying this method of mosquito control. The relation of plants to the production of malaria mosquitoes on the Authority's impounded waters is discussed in detail in a manuscript now being prepared for publication by the Biology Section of the Health and Safety Department.

Accessory Measures

The successful utilization of water level management for malaria control is not solely dependent upon the proper manipulation of water elevations, but depends also upon the carrying out of certain accessory measures. These accessory measures may be outlined as follows:

1. Proper Reservoir Preparation
   A. Reservoir Clearance
   B. Marginal Drainage
   C. Final Reconditioning of the Zone of Fluctuation
2. Wintertime Impoundage
3. Shoreline Maintenance
   A. Annual Shoreline Conditioning
   B. Aquatic Growth Control
   C. Marginal Grazing
   D. Drainage Maintenance
4. Permanent Shoreline Improvement

All of the above accessory measures except permanent shoreline improvement have been adequately discussed by previous authors (Kiker and Stromquist, 1939; Hinman, 1941), and a preliminary account of the use of permanent shoreline improvement measures is given in a paper recently prepared by Bishop and Gartrell (1943). The remainder of the present paper will therefore be limited to a discussion of water level management for malaria control on the reservoirs of the Tennessee Valley Authority.

Water Level Management

There has been a tendency to think of water level management for malaria control merely as water level fluctuation; however, recent developments have shown that under certain conditions the maintenance of a relatively constant pool level may constitute an equally important phase of an effective schedule of water level control. The most suitable schedule of water level management for malaria control on a particular reservoir is dependent upon the type of reservoir and the way in which it is used. On the impoundages of the Tennessee Valley Authority, the following three types of schedules are in current use: (1) Seasonal recession alone; (2) Cyclical fluctuation alone; and, (3) A combination schedule for main river reservoirs. Since the latter type schedule involves the combined utilization of all the common phases of water level management, it will be discussed first.

Water Level Schedule on Main River Reservoirs

The application of water level management for malaria control on the nine main river reservoirs of the Tennessee Valley Authority is complicated by the multipurpose use of these projects, namely, for navigation, flood control, and the generation of hydroelectric power. The controlled discharge of water is frequently desirable to afford adequate depths for navigation below the lowermost dam, and the maintenance of a nine-foot navigation channel on all main river reservoirs limits the extent of seasonal recession; also, the obvious desirability of releasing water through the turbines to provide maximum generation of power places a practical limitation upon the scope of cyclical fluctuation. It has therefore been impracticable to undertake the application of either of these measures alone, and a combination schedule has had to be developed. In developing this schedule, an attempt has been made to fit it as closely as possible to the normal operation schedules of the reservoirs and to keep special requests to a minimum. General observations over a period of years on the relative effectiveness of various types of water control schedules and detailed investigations of the water level relationships of littoral plants have made it possible to gradually improve the program of water level management for malaria control on main river reservoirs. The currently recommended schedule involves the combined use of flood surcharge, maintenance of a relatively constant pool level, cyclical fluctuation, and seasonal recession. The main features of this schedule are illustrated in Figure 1. Each of the four phases of the schedule has its particular function, and these are discussed separately in the following paragraphs.

1. *Spring Flood Surcharge*

Sometime during the late winter or early spring, it is desirable to bring the water level up to the maximum elevation in the flood surcharge zone for a brief period, subsequently drawing it back down

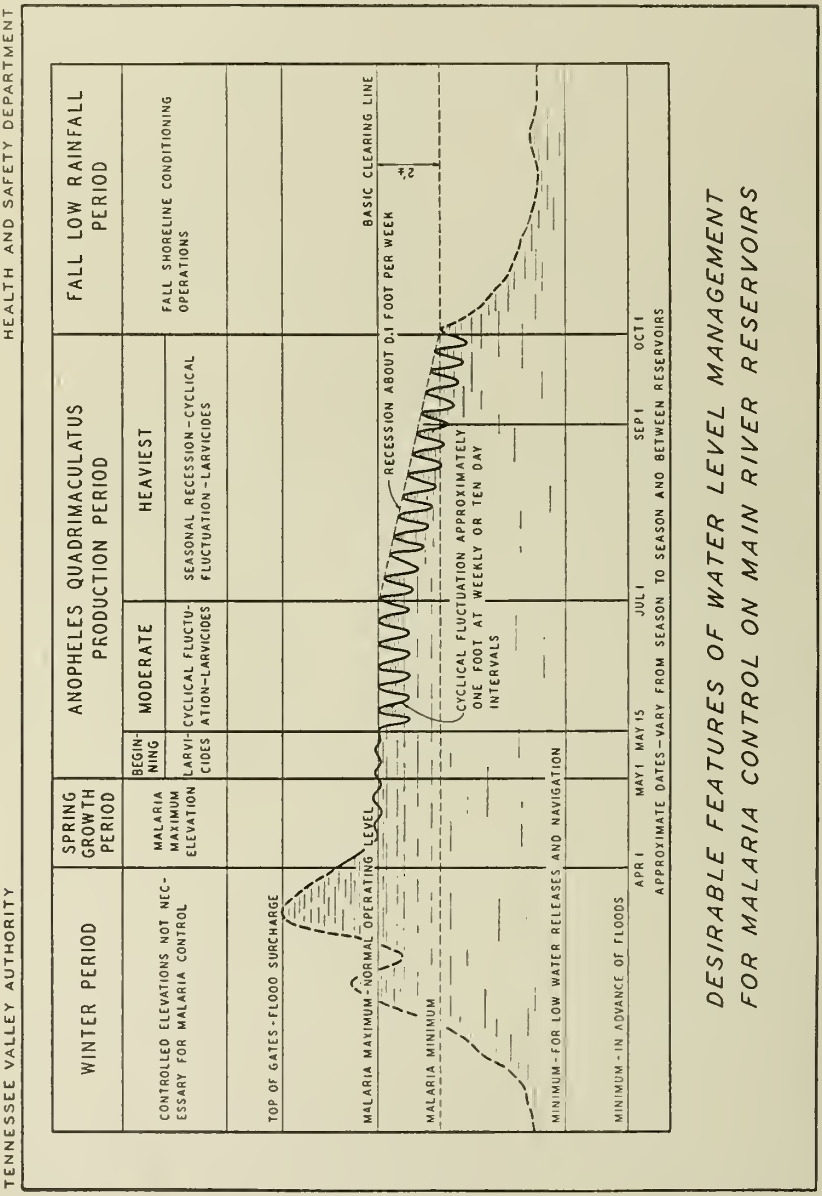

Fig. I—*Desirable Features of Water Level Management for Malaria Control on Main River Reservoirs.*

to the normal maximum summertime elevation (See Fig. 1). This results in the strandage of the winter's accumulation of drift and flotage and thereby prevents this material from creating a mosquito breeding problem later in the season. Thus, the flood surcharge phase is purely a prophylactic measure which aids in preventing the development of suitable breeding conditions for *Anopheles quadrimaculatus*. The annual shoreline conditioning program increases the effectiveness of the use of the flood surcharge through the removal of coppice and stiff-stemmed annuals which would collect drift and flotage off shore and thus prevent its strandage.

The flood surcharge may be effectively used anytime during the late winter or spring when high precipitation and stream flows frequently result in the temporary storage of water in this zone; however, it is desirable that the water not be maintained in the flood surcharge zone for any considerable period after the beginning of the spring growth period, which is usually around April 1 in the lower Valley. The prolonged storage of water in the flood surcharge zone during the growing season results in the killing of timber in this uncleared zone, and this dead timber creates a continuing problem by adding to the accumulation of drift and flotage and through the falling of dead trees into the water. Also, after the beginning of the mosquito breeding season, which is usually between the 1st and 15th of May in the lower Valley, use of the uncleared flood surcharge zone for periods exceeding a week may result in uncontrollable production of *Anopheles quadrimaculatus*. Such objectionable conditions do not result from the use of the flood surcharge zone during the winter season since there is no production of mosquitoes during this period and the dormant trees are not killed by partial inundation.

2. *Maintenance of a Relatively Constant Pool Level During Spring Growth Period*

The second phase of the main river schedule is the maintaining of a relatively constant pool level at the normal maximum summertime elevation from the beginning of the early spring growth period until the beginning of moderate production of *Anopheles quadrimaculatus* (See Fig. 1). The importance of this measure has recently been more fully realized, and its incorporation into the water level management program marks a significant advancement. The function of this constant pool level phase is to prevent the invasion of marginal vegetation into the zone of fluctuation, thus providing for a clean shoreline when the water level is drawn down into the zone by cyclical fluctuation and seasonal recession later in the season; it also decreases the cost of the annual shoreline conditioning program

by narrowing the band of marginal growth and limiting the production of coppice. In the Wilson Dam region, this phase usually begins about April 1 and ends between the middle of May and the first of June. In the upstream reservoirs, the beginning may be delayed a week or two, and the end may be delayed two to four weeks, moderate production of *Anopheles quadrimaculatus* frequently not beginning on these reservoirs until the first part of July. In order to extend this phase and thus realize the maximum growth retarding benefits, light production of *Anopheles quadrimaculatus* during the latter part of the period is controlled through the use of larvicides. At this time of season, vegetation covers are light and larvicides may be applied with a maximum of effectiveness.

A fuller realization of the potentialities of the constant pool phase of water level management has resulted from detailed studies of the water level relationships of the littoral plants normally associated with anopheline production. Observations indicate that seeds of the annual plants which grow in the zone of fluctuation will not germinate until they are dewatered and that woody species, such as willow and buttonball, will remain dormant until the buds are exposed to the air. The maintenance of a relatively constant pool level during the spring growth period therefore retards the normal phenology of the species in the same manner as a late season would, and species which normally initiate growth about April 1 may be held dormant until June 1 or later, depending upon the date when they are first dewatered. The delayed germination of these species results in greatly decreasing their total seasonal growth. For example, willow stumps which initiate growth the first part of April may produce coppice over nine feet tall by the end of the growing season, while those held dormant until July 1 will be less than half this tall. Similar contrasts hold for herbaceous species.

This information on the relation of seasonal water levels to the phenology of littoral plants indicates the importance of holding the water level at or above normal pool during the entire spring growth period. It now appears that even short periods of drawdown may result in the germination of seeds of herbaceous species and the sprouting of coppice which would otherwise be held dormant until later in the season; furthermore, once these plants lose their dormancy, they will continue to grow even though the water is brought back on them, particularly when portions of the stems and leaves project above the water surface. Thus, every effort should be made to hold the water as nearly as possible at a constant pool level, and, when variations are necessary, they should preferably be above normal maximum pool rather than below.

In addition to its function in the malaria control program, the

constant pool phase of water level management affords a real mutual interest with wildlife conservation. Maintaining the normal maximum pool level during the spring growth period provides ideal spawning grounds for bass and other centrarchid fishes and insures that the eggs will hatch and the young fish get well started before the water is drawn down. Thus, a malaria control measure is proving highly beneficial to the fisheries management program of the Authority.

3. *Cyclical Fluctuation*

The third phase of the main river schedule is the use of weekly cyclical fluctuations without seasonal recession (See Fig. 1). Some cyclical fluctuation occurs in the normal operation of the projects. For effective mosquito control, however, it is frequently necessary to augment the scope and regulate the frequency of the normal fluctuations. This is done by varying the loads or discharges at the dams at regular intervals. Such regulation appears to be more feasible on a chain of interconnected plants than would be the case where only one or two projects were involved. Cyclical fluctuation is initiated at the beginning of moderate production of *Anopheles quadrimaculatus* which, in the Wilson Dam region, is usually between the middle of May and the first of June; it ends with the beginning of heavy production of *Anopheles quadrimaculatus* which is usually around July 1. The function of this phase is to bring the water out of the marginal band of vegetation once a week, thus eliminating the intersection line and providing a clean shoreline which is nonproductive of *Anopheles quadrimaculatus.* Recent studies by Rozeboom and Hess (1943) indicate that it is through the creation of intersection line that plants provide adult *Anopheles quadrimaculatus* with optimum conditions for oviposition and supply the larvae with food and protection from natural enemies such as *Gambusia;* thus, the elimination of intersection line by means of the drawdown in cyclical fluctuation would appear to have a threefold effect against *Anopheles quadrimaculatus* and its microhabitat by creating unfavorable conditions for oviposition, interrupting the production of food organisms for the larvae, and exposing the larvae to the predation of their natural enemies. Furthermore, some larvae and eggs are undoubtedly stranded on shore and die from desiccation before the water returns. The return of the water to normal pool level following the drawdown completes the cycle of fluctuation, and this reflooding serves to delay the invasion of marginal vegetation. Thus, while the first two phases of the schedule of water level management on main river reservoirs are directed entirely at the mosquito habitat,

the third phase, cyclical fluctuation, is directed against both the habitat and the mosquitoes.

The moderate production of *Anopheles quadrimaculatus* which marks the beginning of the use of cyclical fluctuation is the result of the invasion of a narrow band of vegetation into the upper limit of the zone of fluctuation. If fairly constant pool levels have been maintained during the spring growth period, this band of vegetation will extend only into the water a few inches at the time cyclical fluctuation is initiated. Therefore, although it is generally agreed that the fluctuation cycle should have an amplitude of about one foot, cycles of considerably less extent may be effective early in the season. For this reason, it is the policy not to make a special request for a full foot cycle of fluctuation until field observations indicate that marginal vegetation has invaded far enough to make it advisable to use this full amount in order to insure adequate control of *Anopheles quadrimaculatus* production. In the use of cyclical fluctuation, it may not be necessary to completely withdraw the water from all marginal plants in order to obtain effective results. Most of the leafy emergent species produce leaves only at or above the water surface, and, if the water level drops down around the bare stems, most of the intersection line is eliminated. Obviously, cyclical fluctuation is relatively ineffective in floating-mat or floating-leaved types of vegetation since these types rise and fall with changing water levels and thus maintain their intersection values. Some plants of these types have appeared in TVA reservoirs and have necessitated the application of special control measures. Attempts to eradicate these species have, in general, proven impracticable; however, measures intended merely to restrict the species within manageable limits have prevented their spreading sufficiently to offer a serious problem.

4. *Combined Seasonal Recession and Cyclical Fluctuation*

The fourth phase of water level management for main river reservoirs is the combining of a seasonal recession of approximately one-tenth foot per week with the regular weekly cycle of fluctuation (See Fig. 1); thus, each week the water level is dropped one foot, but is brought back only nine-tenths of a foot. In the lower Valley, the need for initiating seasonal recession usually begins about July 1, when normal seasonal increases in the mosquito population and the continued invasion of marginal plants result in the beginning of heavy production of *Anopheles quadrimaculatus*. It is significant that this date coincides with the approximate normal beginning of drawing on the main river reservoirs for the development of power and to provide a water supply for navigation. This seasonal recession serves

to insure that at the low level of the weekly fluctuation cycle the water will be drawn far enough out of the advancing band of marginal vegetation to insure adequate control of *Anopheles quadrimaculatus* production. Although the rate of plant invasion obviously varies with a number of factors, a tenth of a foot recession per week is generally sufficient to keep well ahead of it. It is important that seasonal recession should not be in excess of the amount needed to insure adequate mosquito control since such excessive recession results in increased plant invasion, thus broadening the zone from which growth will have to be removed in the fall shoreline conditioning operations. The total amount of seasonal recession is, of course, greatly decreased by the incorporation of the constant pool level phase in the water level management schedule. In general, it appears that two feet of seasonal recession is ample which, combined with one foot available for cyclical fluctuation, would give an overall recession of three feet below the normal pool level. The importance of minimized recession is greatest during the first part of the recession period; sharper recession after about the first part of September is not seriously objectionable since most marginal plants put on very little growth after this date.

The need for specially controlled water levels for malaria control on the main river reservoirs ends about October 1, at which time the breeding of *Anopheles quadrimaculatus* is practically terminated. The use of stored water for the development of power may continue on through the normally dry fall period. Advantage is taken of this normally low water period to complete the marginal growth removal operations of the annual shoreline conditioning program. No special requests are made for controlled water elevations during the winter.

General Comments on the Main River Schedule

From the preceding discussion, it will be observed that the major recent improvements in the schedule of water level management for malaria control on main river reservoirs are the increased emphasis on the use and extended duration of a relatively constant pool level phase and the minimizing of seasonal recession. These phases of the schedule emphasize the importance of water level management in controlling the mosquito habitat in addition to its direct action against the mosquitoes. The effects of water level management tend to be cumulative; a proper seasonal schedule will kill many semi-aquatics and stumps and stubble of woody species and will thus result in a much improved shoreline condition for the following year; conversely, an improper schedule will result in an extension of these species and an increased problem during the following year.

An example of the benefits of the above type schedule is given in the data presented in Figure 2 for Guntersville and Wheeler Reservoirs. During the 1942 season, both of these reservoirs experienced drawdowns during the spring growth period, while in 1943 each had

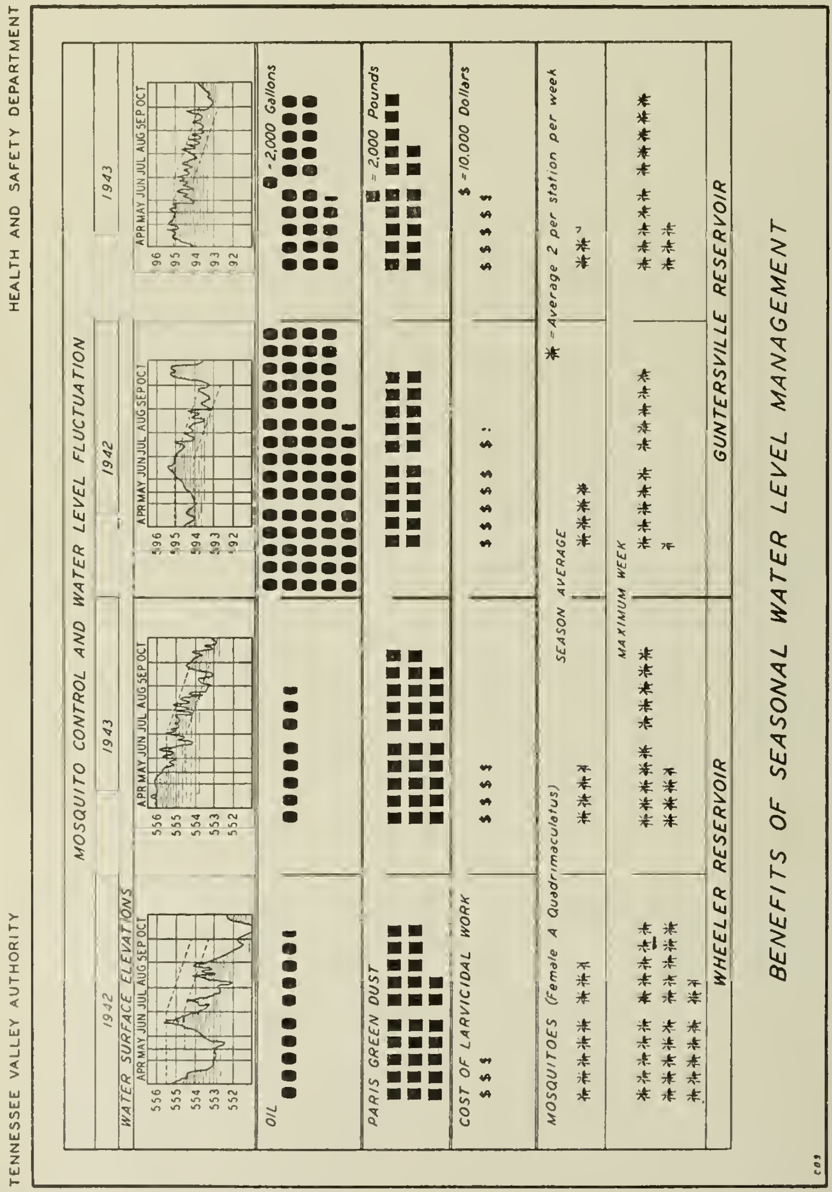

Fig. II—*Benefits of Seasonal Water Level Management for Malaria Control as Illustrated by Wheeler and Guntersville Reservoirs During 1942 and 1943.*

a water level schedule which was a reasonable approximation of the desired schedule outlined above. The resulting increase in the effectiveness of mosquito control and decreased cost of larvicidal treatment and shoreline conditioning is evident from the data presented. The unfavorable water levels on the Guntersville and Wheeler Reservoirs during the 1942 season are typical of the emergencies which develop as a result of the extremes of river flow. Such emergencies are met in the most practicable manner to minimize the degree and length of *Anopheles quadrimaculatus* production. Larvicidal application is intensified and an effort is made to obtain the most favorable compromise on water level management; this might be increased scope of periodic fluctuation or a more rapid recession, depending upon the particular problems presented in the individual reservoir.

Seasonal Recession on Storage Reservoirs

Seasonal recession without cyclical fluctuation is used principally on the Authority's storage reservoirs. In addition to the nine main river reservoirs, the Authority has twelve completed storage reservoirs on the tributary streams and four others are to be completed at a future date. Although power generation is usually incorporated into these projects, their principal function is to store water during the spring rainy periods which is used to maintain stream flows to downstream reservoirs during the dry weather period which usually prevails during the summer and fall. The resulting drawdown during the summer and fall usually exceeds 20 feet and is frequently as much as 40 or 50 feet or more. Thus, the normal operation of the storage reservoirs usually provides satisfactory mosquito control because the summer drawdown keeps the shoreline well ahead of the encroaching band of marginal vegetation, resulting in a clean water surface relatively free from anopheline production. The generally steep shorelines and later season on the storage reservoirs also contribute to the ease of providing adequate mosquito control. As on the main river reservoirs, holding the water levels relatively constant during the spring growth period and delaying the beginning of seasonal recession increases the effectiveness of the water level recession in controlling *Anopheles quadrimaculatus* production; however, these measures are not as important as they are on the main river reservoirs because of the greatly increased range of seasonal recession.

The storage reservoirs serve a most useful purpose in the water level management program for malaria control in that they permit better regulation of downstream reservoirs where the most serious malaria problems exist. Earlier, some of the most serious temporary situations developed as a result of either extreme high or low river flows, necessitating departure from recommended water level sched-

ules. The increase in the number of storage reservoirs has decreased the number and intensity of such unfavorable situations.

The chief difficulties experienced in utilizing seasonal recession for malaria control on storage reservoirs are caused by unseasonal rains which may necessitate bringing the water levels back up into the marginal vegetation during the mosquito breeding season. Such a situation is made even worse if a spring drought has made it impossible to fill the reservoir during the spring growth period, resulting in a heavy invasion of marginal vegetation which creates ideal breeding conditions for *Anopheles quadrimaculatus* when the water is brought into it later in the season. If the summer rise of water into the marginal vegetation is rapid and it is followed within a week or ten days by a rapid drawdown into a clean shoreline again, no serious production of *Anopheles quadrimaculatus* will result; for example, Hiwassee Reservoir was brought to the maximum elevation during the peak of the mosquito breeding season in July 1943, and rapidly lowered again without any discernible increase in anopheline production. However, if the water remains at a constant or gradually rising level in the marginal vegetation for an extended period, heavy production of *Anopheles quadrimaculatus* may result, calling for intensive application of larvicidal measures. The contrast between the effects of seasonal recession and seasonal progression of water levels on storage reservoirs is well illustrated in Figure 3.

Although seasonal recession has in the past been used mainly on the Authority's storage reservoirs, it appears that it will be necessary to use this type of water level management on the new Kentucky Reservoir, the last and largest of the Authority's main river reservoirs which is scheduled for impoundment during 1944. The immense size of this reservoir (185 miles long with a useful storage of over four and a half million acre feet and a normal surface area of 158,000 acres) will make it impossible to apply any regular schedule of cyclical fluctuation, and chief reliance will therefore have to be placed on the use of a seasonal recession of some five feet. Although this amount of recession is much less than that commonly employed on storage reservoirs, recent information indicates that it may be adequate, particularly if it follows a spring flood surcharge and a period of relatively constant normal maximum pool elevation during the spring growth period.

Cyclical Fluctuation Alone

As has previously been pointed out, the requirements of power and navigation generally limit the amplitude of cyclical fluctuation on the Authority's main river reservoirs and thus preclude the use of this measure alone in a water level management program. How-

ever, on Wilson Reservoir, which has the highest generating capacity and lowest water storage capacity of all the main river reservoirs, it has been found possible to obtain cyclical fluctuation of one and one-half to two feet in amplitude in connection with the normal

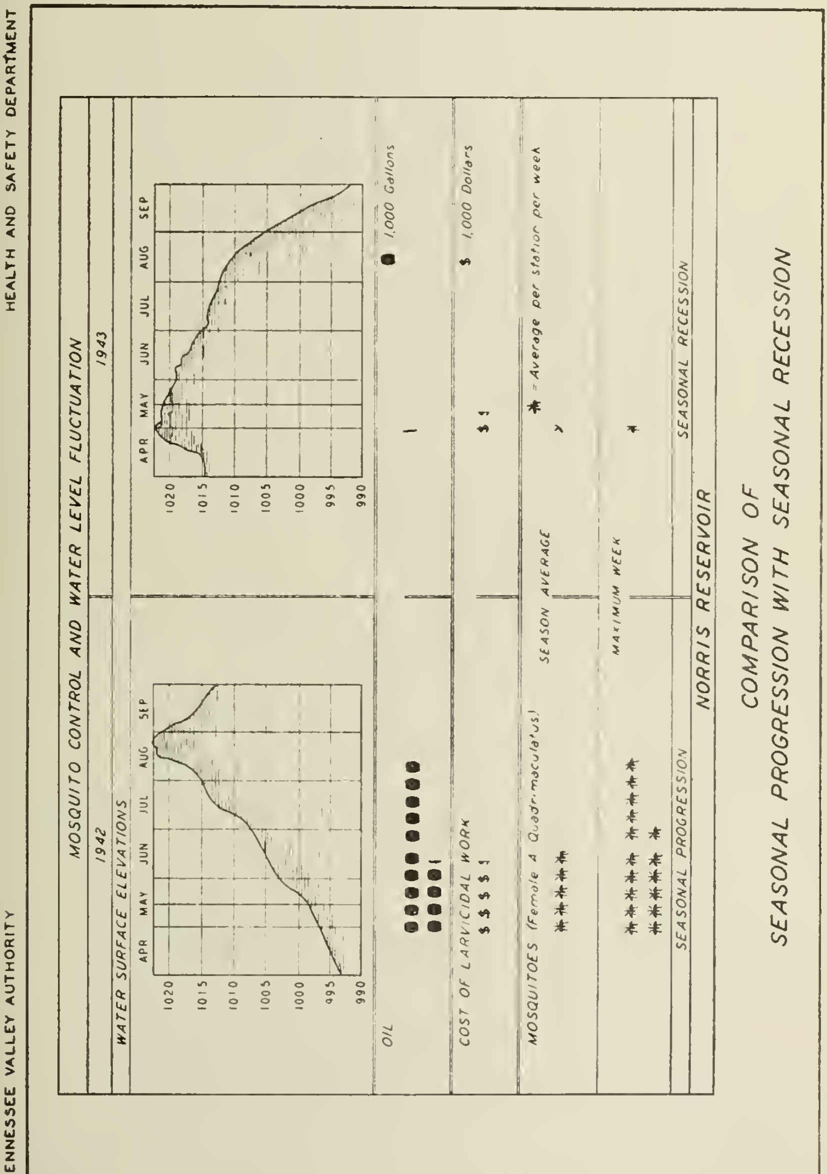

Fig. III—*Comparison of Seasonal Progression with Seasonal Recession as Illustrated by Norris Reservoir During 1942 and 1943.*

operation of the reservoir without spilling water. Such an operation does not interfere with navigation. The lake elevation has been raised approximately two feet during the past year, thus increasing the navigation limits and permitting more flexibility for water level

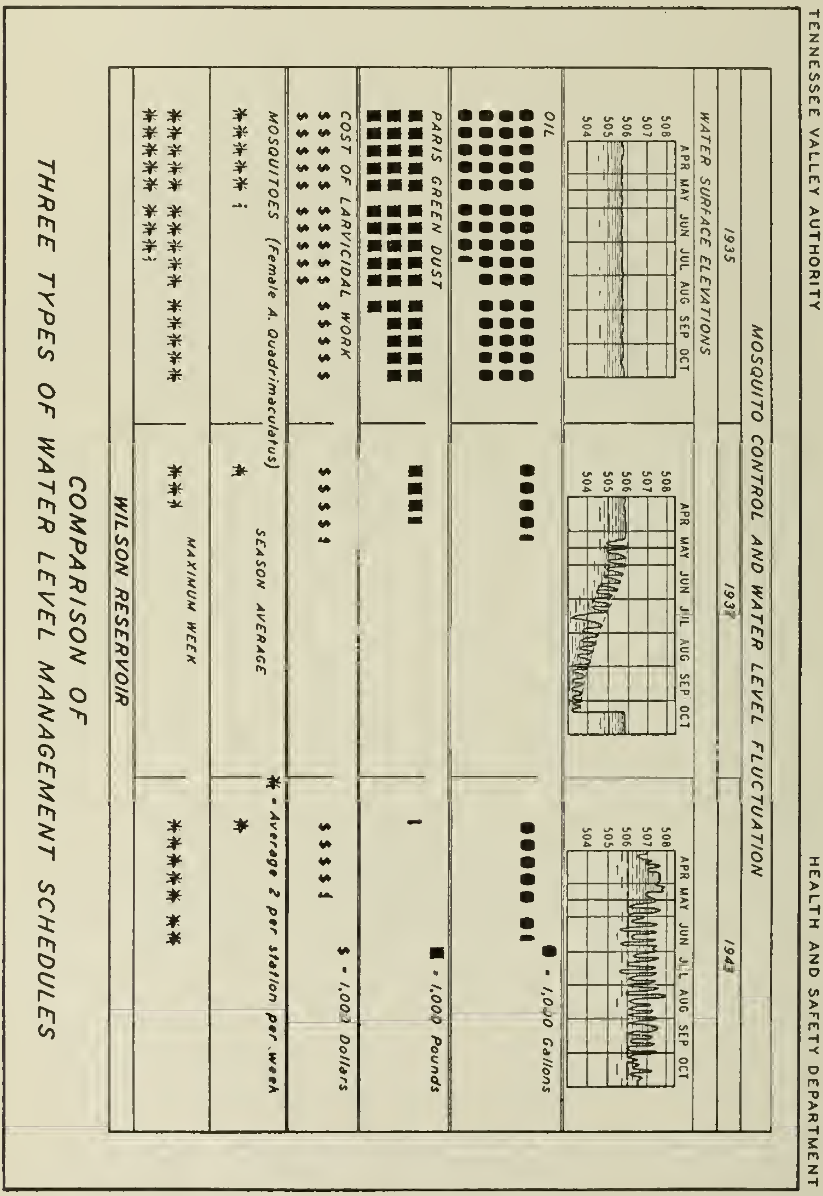

Fig. IV—*Comparison of Three Types of Water Level Management Schedules as Illustrated by Wilson Reservoir in 1935, 1937, and 1943.*

management. During the 1943 season this reservoir was operated on a schedule of cyclical fluctuation of one and one-half to two feet amplitude with satisfactory results, as illustrated in Figure 4. By way of comparison, this graph shows also the results of a schedule combining seasonal recession with periodic fluctuation during the season of 1937 and the very difficult, expensive, and ineffective control encountered during 1935 when it was necessary to maintain the lake at constant level to facilitate construction at Wheeler Dam.

Opportunity is taken here to express appreciation for the cooperation which has been exhibited by various departments in the Authority in executing a successful program of water level management for malaria control. Special appreciation is due those of the Water Control Planning Department who are in immediate charge of planning the regulation of the river system for the overall best interest of these multipurpose projects. Theirs is a Herculean task. Suffice it to say that during the past season of 1943 in the face of wartime power demands, accelerated construction activities, and a multitude of other lesser demands, there was provided the most successful overall program of water level management for malaria control which has yet been experienced on the reservoirs of the Tennessee Valley Authority.

SUMMARY

A review is given of the use of water level management for malaria control on the reservoirs of the Tennessee Valley Authority, particularly with reference to new developments which have taken place since 1940. Accessory measures for water level management are briefly outlined, including reservoir preparation, wintertime impoundage, shoreline maintenance, and permanent shoreline improvement; however, the main portion of the paper is devoted to a detailed discussion of actual water level management schedules.

It is pointed out that three types of water level management are in use on the Authority's reservoirs, namely, (1) Seasonal recession alone, (2) Cyclical fluctuation alone, and (3) A combined schedule for use on the main river reservoirs. Chief attention is given to this latter type since it is the one used on the reservoirs which offer the greatest problems in malaria control. It is stated that the most important new developments in water level management for malaria control on main river reservoirs are the incorporation of a relatively constant pool level phase and the limiting of seasonal recession to the amount necessary for current mosquito control. These new developments have resulted mainly from observations and investigations on the relation of water level management to the reservoirs consists of four phases, each with its own particular func-

tion, as follows: (1) spring flood surcharge, (2) maintenance of constant pool level during the spring growth period, (3) cyclical fluctuation, and (4) seasonal recession combined with cyclical fluctuation. The first two phases are purely prophylactic in that they limit or prevent the development of suitable breeding conditions for *Anopheles quadrimaculatus* later in the season by stranding flotage and limiting the invasion of marginal plants. The third and fourth phases are both prophylactic and curative in that they limit the invasion of marginal plants and also act directly against the mosquitoes by altering their microhabitat, exposing the larvae to natural enemies, and stranding eggs and larvae. The importance of the intersection line evaluation of the anopheline production potentials of marginal plants and flotage in relation to water level management for malaria control is pointed out.

A general discussion is given of the use of seasonal recession without cyclical fluctuation on the storage reservoirs. It is stated that present plans also call for the utilization of this type of a schedule on the new Kentucky Reservoir. The use of cyclical fluctuations of 1½ to 2 ft. in amplitude, without seasonal recession, has given satisfactory control on Wilson Reservoir during the 1943 season.

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AIRPLANE DUSTING FOR THE CONTROL OF *ANOPHELES QUADRIMACULATUS* ON IMPOUNDED WATERS

By C. W. Kruse*, A. D. Hess*, and R. L. Metcalf*

INTRODUCTION

The Tennessee Valley Authority's initial experiences with the airplane as a means of applying dust larvicide for the control of *Anopheles quadrimaculatus* on its impoundages were described by Watson (1936), and later progress was reported by Watson et al (1938) and Kiker et al (1938). In keeping pace with the impounding of new reservoirs it has been necessary to expand the initial one airplane operation used in a single reservoir to five dusting airplanes expected to be in use next season carrying out dusting operations on eight reservoirs. With this expansion have come further developments, and it will be the purpose of this paper to discuss briefly major improvements since the work was last reported on in 1938. These improvements have involved mainly the mechanics of the duster, method of calibration, general field treatment practices and methods for measuring the distribution and effectiveness of the dust, and specifications for purchasing Paris green with particular reference to particle size. These will be discussed in the order given. The detailed information upon which these discussions are based is given in the unpublished reports listed in the bibliography.

DUSTING AIRPLANE

The first airplane used by the Tennessee Valley Authority on routine dusting was a conversion from the open land Stearman Model 4-DX biplane. This exceptionally rugged model is one of the few commercial airplanes manufactured in the early nineteen thirties before extensive streamlining and paved airports were in general use. Thus, it has a relatively low cruising speed of 90 to 100 mph, high lift, and good payload characteristics, all of which are desirable for operations from short rough fields. Experience indicates that this slightly antiquated commercial biplane, too expensive for

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most private pilots and too slow for cross-country commercial operations, meets, with a minimum of alterations, the requirements for a good dusting plane.

When it became necessary to make the first expansion of the Authority's dusting operation in 1937, it was decided for purposes of comparison to parallel the dusting operations of the Authority's airplane with those of a contract plane. The work was advertised, and the Delta Air Corporation, one of the leading crop dusting organizations in the South, was low bidder. During the following four years the Delta Air Corporation supplied an airplane and pilot for a stipulated amount per flying hour with a minimum seasonal guarantee. The contract flying was highly satisfactory in every respect and the corporation's field representative, Mr. B. R. Coad, made helpful suggestions for improving the mosquito control dusting practices. However, a special study and report prepared in 1940 pointed to the economy of the Authority either contracting for all airplane dusting or handling it with its own equipment. There was little choice, but decision was eventually reached to use a Tennessee Valley Authority service since the Authority maintained an airplane section in its Transportation Division and then owned two dusting ships. In addition, retaining the service within the Authority promised greater flexibility in executing unforeseen emergency work.

The retaining of the airplane dusting service within the Authority and the extension of the service to new reservoirs have required the purchase of additional airplanes. All of these have been the same model Stearman so that parts are interchangeable, a most important feature of a multiplane operation. As the additional second hand airplanes were purchased, they were completely overhauled with the dusting equipment being literally built into them. Most important has been the installation of modernized Pratt and Whitney 450 horsepower Wasp engines to replace the initial lower horsepower units. Two types of propellors are used with the Wasp engine, namely, the two-position Hamilton Standard and the Hamilton constant speed. The two-position propellor provides, through manual control, the low pitch for short take-off under heavy load and steep pull-up over obstacles; the high pitch position is used during normal level flight. The constant speed propellor is an automatic feathering device for accomplishing the above under various flight conditions. Some of the dusting pilots appear to favor the two-position propellor since it gives instantaneous response, whereas the constant speed propellor has some lag; however, from the standpoint of engine maintenance, the constant speed propellor is easier on the power plant.

In contrast to the monoplane, the biplane appears particularly

suitable for airplane dusting. The relatively shorter wing span permits steeper low altitude turns and safer access through narrow flight lanes in addition to requiring less hangar space. The external bracing

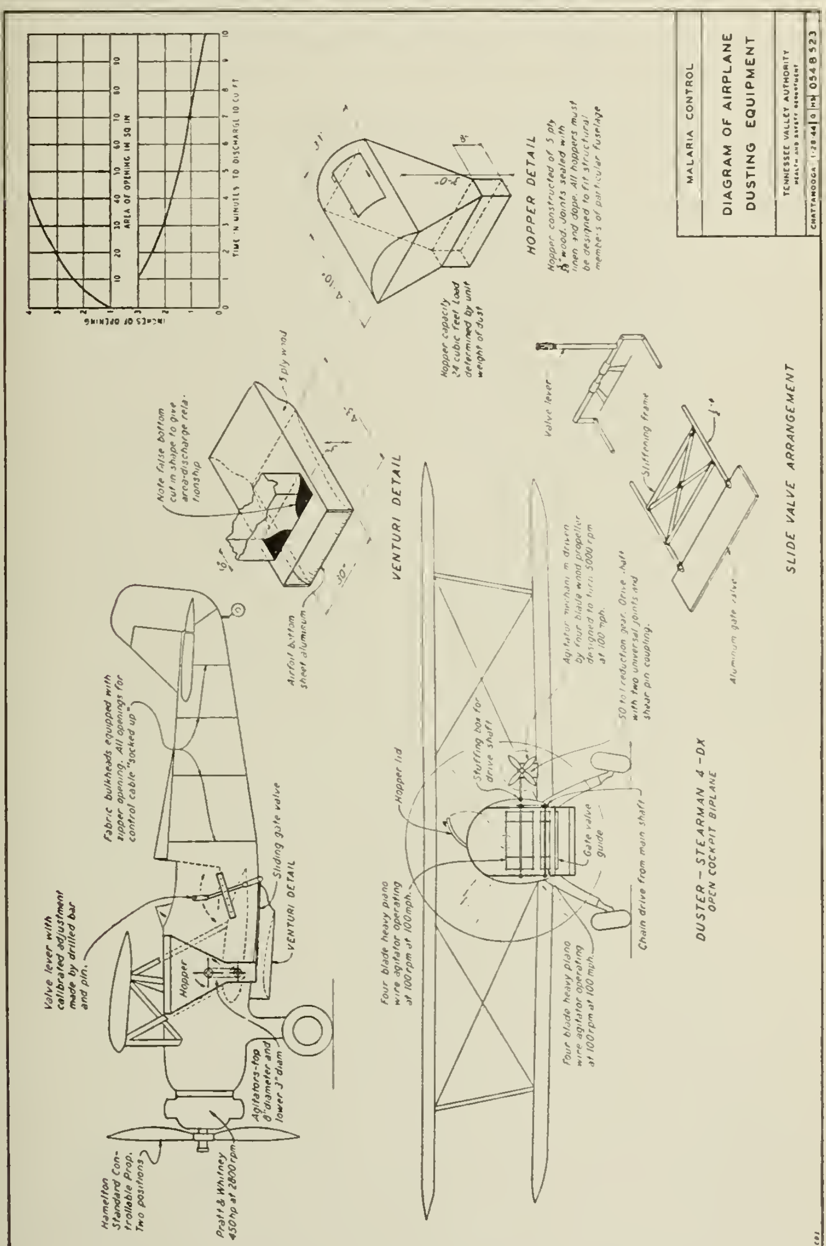


Plate I—*Diagram of Airplane Dusting Equipment.*

of biplanes with sturdy struts and flying and landing wires make up an efficient truss system. This rugged feature has proven very important since, in spite of reasonable preventive measures, a few obstructions such as telephone wires and tree tops have been hit in flight causing considerable damage to the wing and yet, in every instance, sufficient lift remained to maintain flight back to the base. No unnecessary risks are run, but it is gratifying to the pilots to know that they are flying a rugged and reliable airplane.

It is frequently desirable to fly the dusting areas just before daylight, and all ships are therefore equipped with navigation lights and illuminated instrument panels. A small rear-view mirror greatly facilitates observation of the dust cloud while in flight.

The installation of the dust hopper, venturi, and agitators and valve is shown diagrammatically on Plate I. The hopper is installed in the space originally provided for the forward passenger cockpit. It is acknowledged that some additional visibility could be acquired by piloting from the forward cockpit, but, since the load diminishes as the dust is discharged, considerable "trimming" of the ship during flight would be required if the load were not carried near the center of lift. Sometimes it is necessary to alter the structural members of the fuselage in order to hold the hopper. These changes must be carefully checked and approved by the Civil Aeronautics Administration for air worthiness. The 24 cubic foot hopper is constructed of five-ply wood fastened to an oak frame which is bolted to the fuselage members. The metal hoppers, used initially, proved unsatisfactory due to structural failures resulting from vibration. Lightness and strength are of utmost importance. The interior corners of the hopper are packed with a sealing compound and covered with a doped linen strip. This presents a smooth, dust-tight joint that will withstand the vibrations of the ship in flight. The steep sloping sides of the hopper direct the dust into a throat which extends vertically through the bottom of the fuselage into the dust discharge venturi. Directly above the throat is placed a six-inch diameter open drum type piano wire agitator, with a similar three-inch diameter agitator located within the throat directly above the outlet into the venturi. These agitators cut up the dust providing a uniform flow into the venturi regardless of the amount of dust within the hopper. A four-bladed, wooden, wind-driven propellor and reduction gear located on the leading edge of the lower wing provide the driving force through a main shaft to the upper six-inch agitator. The shafting penetrates the wall of the hopper through a packing nut bearing which holds out the dust. The lower agitator is operated by a sprocket and chain drive off the main shaft which is located outside the hopper but within the fabric covering of the fuselage.

The pitch of the wind-driven propellor is designed so as to turn up to five thousand r.p.m. at a flying speed of 100 m.p.h. and through reduction gears the agitators are driven at 100 r.p.m. in a counter-clockwise direction. On the floor of the hopper is fitted a simple sliding gate valve supported on either side by guides which seat the valve into a sealing strip.

In order to obtain a sensitive control on the volume of dust discharged at various valve openings, a thin gauged metal plate has been fitted on the floor of the hopper just above the valve opening and cut out in such a manner as to give a parabolic increase in areas of opening for each increasing valve setting (See Plate I). The sliding valve is constructed of sheet aluminum and is operated by a hand lever located in the left side of the pilot's cockpit. It was necessary to rigidly brace the tension members which move the valve to prevent any imperfect seating against the sealing strip which would allow dust to leak out. The valve lever is guided against a metal strap within the cockpit into which are drilled holes for the required valve setting. The valve opening is set by the use of a small steel pin which is inserted into the strap guide, and this pin stops the lever at the proper place when it is pulled back to open the valve.

The venturi is actually a half venturi. The six by thirty inch mouth is rectangular in shape with vertical plywood side walls. The major constriction is accomplished by a sheet aluminum bottom panel which is built up into an airfoil section having a 43-inch chord very similar in appearance to an airplane wing section. The maximum depth of the venturi is 8 inches, and the depth at the point of maximum constriction is 3 inches. This point of maximum constriction is located directly beneath the valve opening. The venturi is fastened against the bottom of the fuselage which serves as the top of the venturi structure. All fittings and fastenings are made firm against vibration and safetied in accordance with good aviation practice.

It was early found necessary to carefully control the entrance of loose dust into the ship. Not only was it hazardous to have arsenical dust impinging on the face and neck of the pilot, but, after a season's operation, it was not uncommon to collect a hundred pounds or so of dust from the fuselage and wing. It appeared that after carefully fitting and sealing the hopper and hopper lid into the fuselage still sizable amounts of dust drifted forward along the fuselage from the tail group into the cockpit and lower wing panels. This problem was not satisfactorily solved until every control opening into the ship along the sides and bottom from the hopper back was "socked up" with tight woven cloth. In addition, four doped linen bulkheads were installed within the fuselage between the tail group and cock-

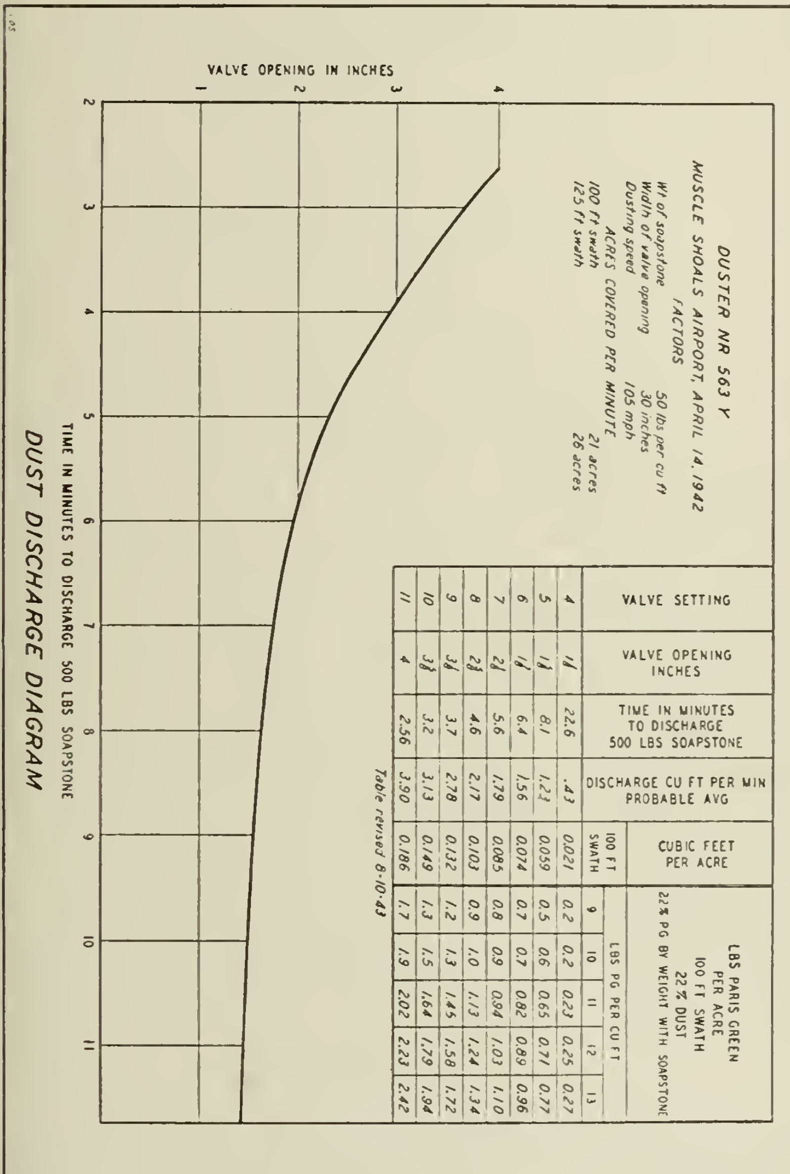
pit. Every precaution is exercised during dust loading operations to prevent the entrance of loose dust into the cockpit. Usually after the lid is secure on a loaded hopper, the surface of the fuselage in front of the cockpit is carefully brushed off before the motor is started.

In general, the field application of dust is the same as previously reported (Watson et al, 1938; Kiker et al, 1938). The dust is applied during the three to four hours of early morning calm with as low flying as is necessary for dust cloud control, usually 20 to 30 feet above the breeding surface. Any considerable wind movement will seriously interfere with the application of dust. Since the calm period is limited, everything is done to cut down the non-dusting flying time. This is principally accomplished by careful routing to prevent backtracking and by the convenient location of loading strips. Any reasonably level and smooth strip of land approximately 300 feet wide by 2,000 feet long with clear approaches serves satisfactorily as a loading strip. It is the current practice to remove isolated or small groups of trees where they obstruct airplane dusting along the reservoir margins. Included in the specifications for marginal clearing and drainage for new impoundments is a section providing for such marginal clearing to facilitate airplane dusting.

In recent years more emphasis has been placed on pilot training, not only in pilotage, but also in the fundamentals of anopheline control. Such training is essential to the efficient application of dust. After the general areas are set out for treatment on the basis of inspections for larvae, the pilot must assume the responsibility for the detailed pattern of treatment.

DUST VALVE CALIBRATION AND DUST MIXING AND TAGGING

The rate of dust application is expressed in pounds of Paris green per acre, and the valve calibrations are made accordingly. Three variables enter into the calibrations, namely, the normal dusting speed, the discharge characteristics of the venturi, and the density of the dusts used. All swaths are assumed to be 100 feet wide, and the calculation of discharge rates in pounds per acre is made on this basis. There are some minor variations between ships, but, generally, with the assumed 100 foot swath, an average of 21 acres per minute can be treated. The discharge characteristics of the venturi at different valve settings are carefully plotted, using a stop watch to determine the time of discharging equal volumes of soapstone. In this manner, a discharge curve is developed for each ship as shown in Plate II. It may seem that all discharges at the various



VALVE SETTING	VALVE OPENING INCHES	TIME IN MINUTES TO DISCHARGE 500 LBS SOAPSTONE	DISCHARGE CU FT PER MIN PROBABLE AVG	CUBIC FEET PER ACRE 100 FT SWATH	LBS PARIS GREEN PER ACRE 100 FT SWATH 22% DUST — 22% PG BY WEIGHT WITH SOAPSTONE — LBS PG PER CU FT: 9	10	11	12	13
4	1⅛	22.6	.43	0.021	0.2	0.2	0.23	0.25	0.27
5	1⅜	8.1	1.21	0.059	0.5	0.6	0.65	0.71	0.77
6	1⅝	6.4	1.56	0.074	0.7	0.7	0.82	0.89	0.96
7	2⅛	5.6	1.79	0.085	0.8	0.9	0.94	1.03	1.10
8	2⅜	4.6	2.17	0.103	0.9	1.0	1.13	1.24	1.34
9	3⅛	3.7	2.78	0.132	1.2	1.3	1.45	1.58	1.72
10	3⅜	3.2	3.13	0.149	1.3	1.5	1.64	1.79	1.94
11	4	2.56	3.90	0.186	1.7	1.9	2.02	2.23	2.42

Table revised 8-10-43

Plate II—*Dust Discharge Diagram.*

openings are carried through a tabulation converting from cubic feet of dust per minute to cubic feet of dust per acre, thence to pounds of Paris green per acre. This is accomplished through arithmetical computation from column to column. Paris green and soap-

stone, the ingredients of our larvicidal dust, vary in density from shipment to shipment, and therefore the last columns of the calibration chart give discharge rates in pounds Paris green per acre with dust mixtures varying within the normal range from 9 to 13 pounds of Paris green per cubic foot of mixed dust.

A central mixing plant, having a capacity of from three to four tons of mixed dust per day, is centrally located in the Valley and supplies dust for all operations. This dust mixing machine was purchased after some unsatisfactory efforts to employ make-shift mixing devices. The mixer was supplied by the Robinson Company, Muncie, Pennsylvania, and as a protective measure was subsequently outfitted with a special dust exhaust system. Shipments of materials are received in carload lots and are mixed, bagged, and tagged soon thereafter. Since the physical characteristics of the dust supplied by different manufacturers vary somewhat, an effort is made to keep the different shipments separated in the field as much as possible. The weights per cubic foot of soapstone, Paris green, and the mixture are determined for each shipment. The standard mixture is 22.2% Paris green by weight. The fraction figure results from the combination of one 100-pound can of Paris green with seven 50-pound sacks of soapstone. A three-ply, waterproof paper bag is used for sacking, and 50 pounds of the mixed dust are placed in each bag. The sacks can be reused a number of times.

A tag is attached to each newly mixed sack of dust, giving desired information for the field operation. This includes the name of the manufacturers supplying the Paris green and soapstone, their respective weights per cubic foot, and the pounds of Paris green per cubic foot of mixed dust. The pounds of Paris green per cubic foot of mixed dust is the figure used by the field forces for obtaining the proper valve opening from the calibration chart. The tagging provides needed information in applying and checking on the effectiveness of the dust and serves as a permanent identification for the various shipments.

FIELD DISTRIBUTION

During the past five years extensive investigations have been made of the dust distribution and larvicidal effectiveness of airplane dusting with Paris green. Larvicidal effectiveness has been determined by standard dipping procedures. Dust distribution was at first determined by the particle count method, but since 1940 a method of quantitative chemical analysis for arsenic has been used (Asc. Agr. Chem., 1940) which makes it possible to determine the actual amount of Paris green reaching any point on the dusting swath.

In Plate III is given a representative particle count distribution curve and the average distribution curve in per cent recovery as determined from approximately 60 individual tests using the method of quantitative chemical analysis. Both curves are noticeably

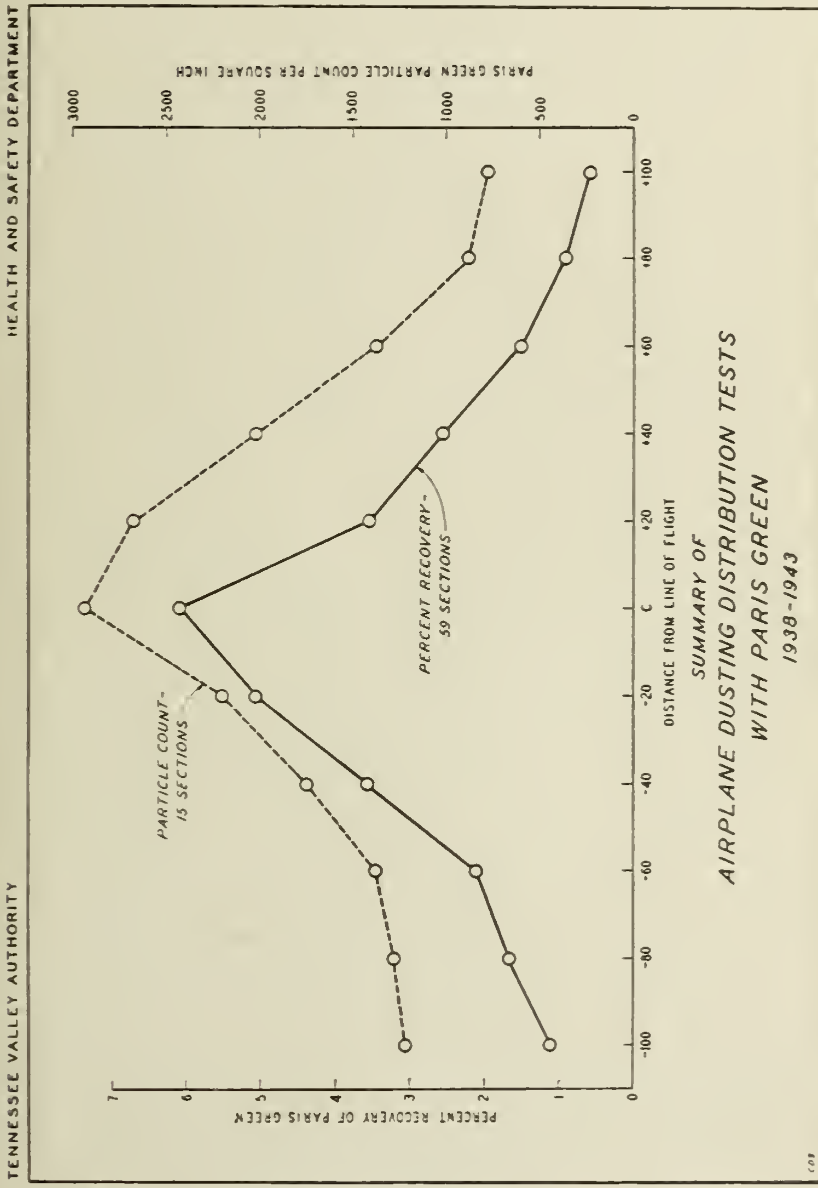


Plate III—*Summary of Airplane Dusting Distribution Tests with Paris Green, 1938-1943.*

skewed to the left which is believed to be due to propellor torque. The two curves are quite similar, the principal difference being that the particle count curve does not drop off so rapidly at the outer edges. This is probably due to the fact that the larger particles fall in the center and the smaller particles drift to the side, thus giving disproportionately high counts at the outer edges.

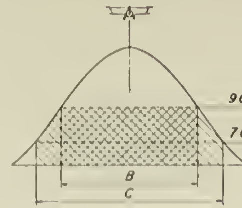
The per cent recovery curve indicates that of the total dust discharged about 28 per cent falls in a swath 200 feet wide and of this over 20 per cent falls in the center 100 feet of the dusting swath. Thus, over 70 per cent of the dust drifts away from the treatment area and for practical purposes may be considered lost. This low per cent recovery is believed to be due in large part to the fact that commercially available Paris greens, which are manufactured for agricultural use, are of too fine a particle size for most effective distribution by airplane. The possibilities of obtaining a larger particle size Paris green for use in airplane dusting have therefore been investigated, and preliminary field tests with some of these dusts have given promising results. These large particle size Paris greens will be considered further in the discussion of specifications for Paris green.

Along with the studies on dust distribution, investigations have been made of the relative effectiveness of varying amounts of Paris green under different conditions of plant cover. Although these investigations are not yet completed, sufficient information is already available to provide a fairly reliable guide for field operations. On the basis of the data now available, an actual recovery of 0.2 pounds of Paris green per acre (not to be confused with calibrated rate of discharge) will give a larval kill of about 90 per cent under conditions of light plant cover (0-35%); 0.6 pounds per acre will be required to obtain a 90 per cent kill under conditions of medium plant cover (35-65%); and with a heavy plant cover (65-100%), 1.2 pounds will be required. Similarly, a 70 per cent kill may be expected with recoveries of about 0.1, 0.3, and 0.6 pounds per acre under respective conditions of light, medium, and heavy cover.

By combining the information on dust distribution and larval kills, it is possible to estimate effective swath width for airplane dusting under varying conditions of plant cover, rates of discharge, and distances between flights. This has been done, and the results are presented in Plate IV. By reference to this plate, the most effective discharge rates and distances between flights may be determined for varying field conditions.

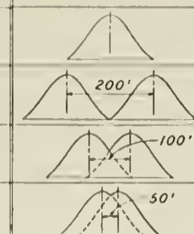
TENNESSEE VALLEY AUTHORITY — HEALTH AND SAFETY DEPARTMENT

B = WIDTH IN FEET GIVING AT LEAST 90% KILL
C = WIDTH IN FEET GIVING AT LEAST 70% KILL



REQUIRED RECOVERY OF PARIS GREEN IN POUNDS PER ACRE

	PLANT COVER		
	LIGHT	MEDIUM	HEAVY
90% LARVAL KILL	0.2	0.6	1.2
70% LARVAL KILL	0.1	0.3	0.6

LARVAL KILL IN %	EXPECTED WIDTHS IN FEET OF INDICATED LARVAL KILL									SWATH TREATMENT
	LIGHT COVER LBS P G PER ACRE 100' SWATH			MEDIUM COVER LBS P G PER ACRE 100' SWATH			HEAVY COVER LBS P G PER ACRE 100' SWATH			
	1.0	1.5	2.0	1.0	1.5	2.0	1.0	1.5	2.0	
AT LEAST 90% KILL	50	90	115	0	0	20	0	0	0	
AT LEAST 70% KILL	115	160	180	20	50	80	0	0	20	
AT LEAST 90% KILL	115	240	300	0	0	40	0	0	0	200'
AT LEAST 70% KILL	300	350	380	40	115	175	0	0	40	
AT LEAST 90% KILL	160	210	230	0	0	40	0	0	0	100'
AT LEAST 70% KILL	230	255	280	40	160	200	0	0	40	
AT LEAST 90% KILL	130	170	190	0	55	90	0	0	0	50'
AT LEAST 70% KILL	190	230	265	90	130	155	0	30	90	

EFFECTIVE SWATH WIDTHS FOR AIRPLANE DUSTING WITH PARIS GREEN UNDER VARYING CONDITIONS OF PLANT COVER, RATES OF DISCHARGE, AND DISTANCES BETWEEN FLIGHTS

Plate IV—*Effective Swath Widths for Airplane Dusting with Paris Green Under Varying Conditions of Plant Cover, Rates of Discharge, and Distances Between Flights.*

SPECIFICATIONS FOR PARIS GREEN FOR USE IN AIRPLANE DUSTING

Paris green is purchased in large quantities on the open market and consequently the low bidder supplies the material. A certified analysis of the product confirming the specification must accompany the shipment; however, the testing of the toxicity to anopheline larvae is undertaken in the Authority's laboratory before the Paris green is accepted. The present specifications for Paris green are as follows:

> The Paris green must be of a fineness such that approximately 100% will pass a 200 mesh screen and approximately 85% pass a 325 mesh screen. It must contain approximately 55% arsenous oxide with no more than 3½% being soluble in water (all percentages by weight). The Paris green must be lethal to anopheline larvae when applied in natural breeding areas and shall weigh not metal or fiber drums containing 100 pounds of Paris green. Drums shall not exceed in size 15" diameter by 18" high.

From the above discussion on airplane dust distribution, it is apparent that in preparing specifications we are confronted with two conflicting factors. In general, the finer the particle size, the more toxic will be the Paris green to *Anopheles* larvae; however, when applying the material by airplane even slight breezes will cause the dust to drift away if the particles are too fine.

Studies conducted during recent years have been aimed at determining the particle size specifications which would insure that the particles would be small enough to be ingested and effectively toxic against the larvae, and yet large enough that they could be distributed by airplane without excessive drift. From the information now available, the following tentative revision has been made of that portion of the specifications which refer to particle size:

> At least 95% shall pass a 200 mesh screen and at least 85% shall pass a 325 mesh screen; at least 75% shall consist of particles 20 microns or greater in diameter (all percentages are by weight).

Leading manufacturers are of the opinion that a Paris green meeting these specifications can be produced commercially without materially increasing the cost.

SUMMARY

Major improvements in airplane dusting for the control of *Anopheles quadrimaculatus* on the reservoirs of the Tennessee Valley Authority since 1938 have involved mainly the mechanics of the duster, methods of dust valve calibration and dust mixing and tagging, the application and evaluation of general field treatment practices, and specifications for Paris green with particular reference to particle size.

A detailed description is given of the dusting plane and the dust hopper, agitators, release valve, venturi, and other special equipment. The type and location of loading strips, training of pilots, etc. are also briefly discussed. The methods of calibrating the rates of discharge and the mixing and tagging of dust are described.

The dusting operation is carried out during the calm period of early morning, and the flying height is usually 20 to 30 feet. Dust distribution has been determined, both by particle counts and by quantitative chemical analysis. The dust distribution curve is noticeably skewed to the left, probably due to the torque of the plane propellor. It appears that about 20 per cent of the Paris green released falls in the central 100 ft. of the dusting swath and another 8 per cent falls in the second 100 ft.; the remainder of the dust drifts away from the treatment area and for practical purposes may be considered lost. A chart is presented which shows effective swath widths of 70 per cent and 90 per cent larval kills under varying conditions of plant cover, rates of discharge, and distances between swaths.

Studies on ingestibility, toxicity, and field distribution in relation to particle size indicate the desirability of obtaining a Paris green for airplane dusting of a larger particle size than the ordinary commercially available material. A tentative revision is suggested for the particle size specifications for Paris green which is to be used in airplane dusting for malaria control.

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PERMANENT WORKS FOR THE CONTROL OF ANOPHELINES ON IMPOUNDED WATERS

(A preliminary report with particular reference to the Kentucky Reservoir of the Tennessee Valley Authority)

By E. L. Bishop and F. E. Gartrell

The major construction program of the Tennessee Valley Authority for development of the Tennessee River is nearing completion. The series of dams required for flood control, navigation, and power development impounded an extensive chain of fresh water lakes on the main river and its several tributaries. It has been demonstrated that the creation of artificial impoundages in the Southeastern United States usually results in problems of malaria control, and the Tennessee River development has proved to be no exception. Combinations of natural topography, fauna, flora, climate, and the multi-purpose character of the developments in the Tennessee Valley have presented malaria control problems of an extent and intensity, particularly in the lower Tennessee River Valley, not heretofore encountered in the Southeastern United States. Their scope may be appreciated from the facts that, with the completion of the remainder of the 24 projects, there will be a total water surface of 735,000 acres and 10,000 miles of shoreline. Nine of the projects are on the main river and fifteen on the tributaries. The Kentucky Reservoir, scheduled for impoundage during 1944, is the last, and by far the largest, main river reservoir. It reaches from Pickwick Dam, near the Tennessee-Mississippi line, across Tennessee and into Kentucky near the confluence of the Ohio and Tennessee Rivers, a distance of 184 river miles. Figure I shows the location of the Kentucky project with respect to the other developments.

The topography in the region of the Kentucky project is generally flat and this is especially true of the immediate floodplain which will average at least two miles in width. As in the case of some of the other reservoirs in the lower valley, this flat floodplain will be inundated to a considerable depth in the lower portion of the reservoir, and with proper clearing and water level management, presents no unusual difficulties since the new shoreline follows the higher, rolling topography bordering the floodplain and can be controlled with the usual anti-larval measures. The upper reaches of the reservoir will be confined largely to the steep banks of the river and, therefore, no particularly difficult problems are anticipated. In

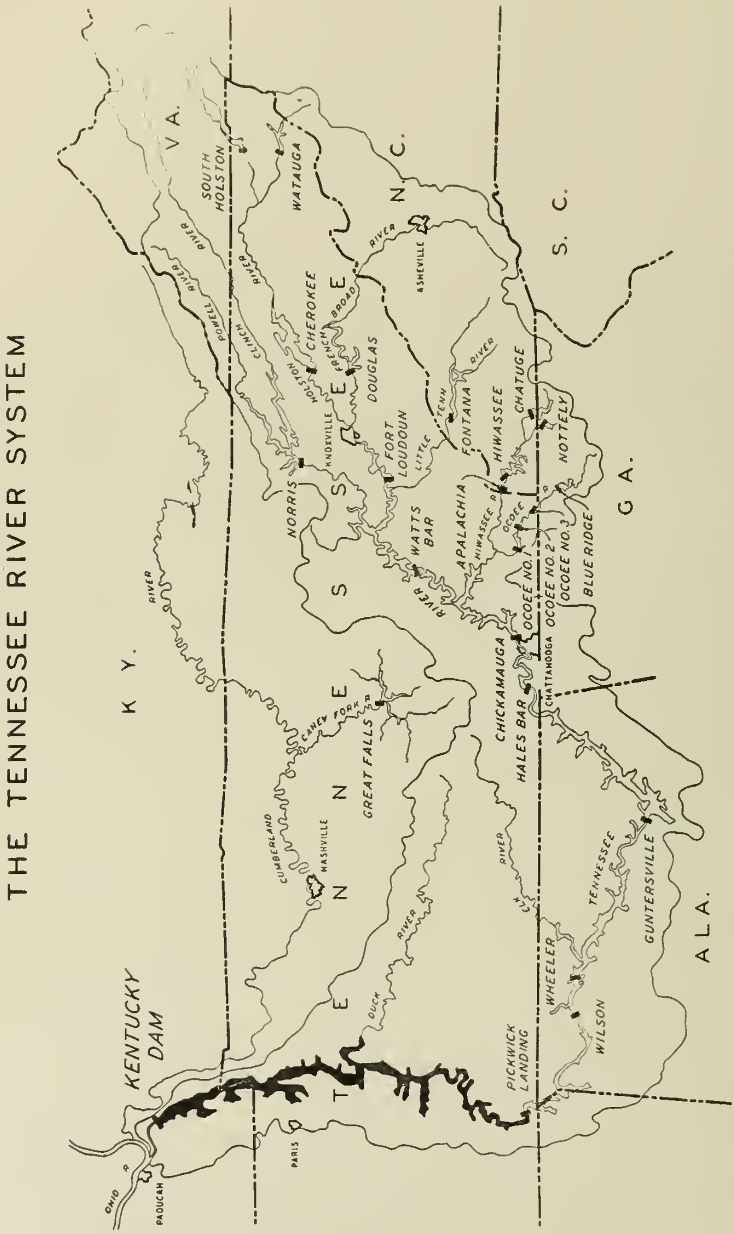

Fig. I–*The Tennessee River System Showing the Location of the Kentucky Reservoir.*

the central part of the reservoir, however, the impoundage will inundate the broad, flat floodplain of alluvial formation to a shallow depth, a combination of circumstances certain to result in an environment highly favorable to excessive *A. quadrimaculatus* production. Here, therefore, is the major problem which confronted the malaria control staff in planning the program and facilities to prevent malaria transmission as a result of the impoundage.

Prior to the advent of the Tennessee Valley Authority in 1933, a practice for malaria control on impounded waters had been developed in the Southeastern United States which, in general, was satisfactory and effective for the type of projects impounded up to that time. The pools of that period were usually for a single purpose, of limited size, and impounded in regions of rough or rolling topography. Control practices and principles had been crystallized into various state regulations governing impounded water and, in general, provided for clearing reservoirs prior to impoundage, draining depressions in the zone of water level fluctuation, and maintaining a clean shoreline or applying larvicides after impoundage to the extent necessary to prevent *A. quadrimaculatus* production.

The Health and Safety Department of the Tennessee Valley Authority began applying the practice then recognized as effective with the beginning development of the Tennessee River. One of the first projects authorized was the Wheeler Reservoir in North Alabama, a territory of exceedingly flat terrain long recognized as an area of high malaria incidence. A preimpoundage malaria survey in 1934 revealed a parasitemia rate of 27% in a rural population of some 24,000 people living within one mile of the proposed reservoir. The project was impounded in 1937 and the usual antilarval control measures have proved quite costly and incompletely effective, in spite of improvement in reservoir antilarval maintenance operations including airplane dusting and the use of especially adapted marginal growth removal equipment. In attempting to cope with *A. quadrimaculatus* from the reservoir itself as well as from bordering natural pondage not affected by the impoundage, it was finally decided to employ house mosquito-proofing in the most critical areas as a secondary means of providing essential protection, and this measure was rather extensively applied with the full approval and participation of the Alabama Department of Public Health. Actual transmission has been controlled as evidenced by the results of annual malaria surveys, but satisfactory control of *A. quadrimaculatus* has not been achieved. We have, therefore, yet to develop permanent solutions for portions of this reservoir.

With the difficulties being encountered in the Wheeler Reservoir in 1937 and 1938 when the Kentucky Reservoir was under-

going the initial stages of planning, it became clearly evident that new approaches to malaria control for projects of this scale and character were necessary. It was our belief that the basic purpose should be to actually build mosquito breeding areas out of the reservoir which affected an estimated 25,000 people living in flight range of approximately 2,000 miles of shoreline. At normal pool there are about 159,000 acres of water surface; hence, quantitatively, the problem is about twice that of the Wheeler Reservoir. Qualitatively it is of at least equal, if not greater, intensity. In addition, there are definite limits to the possibilities for favorable water level management and there is an unusual drainage maintenance complication associated with the sand and silt carried by tributary streams and several agricultural drainage projects contiguous to and extending into the reservoir.

Records of state and county health departments, plus investigations made by the Tennessee Valley Authority, indicate that malaria transmission at times has been a significant problem throughout the length and breath of the reservoir area. More recently there has been a decline in prevalance, which more or less parallels the decline in adjoining regions of the South, despite heavy and continuous *A. quadrimaculatus* production from natural sources as measured by catching station averages over a preimpoundage period of three years. Morbidity and mortality reports on malaria in the South indicate the occurrence of high and low cycles. Obviously, our plans for control must be based on peak rather than minimal prevalence.

It was soon apparent that several years of surveys and studies would be required in the development of the factual background essential as the foundation of a system of permanent control facilities. It was equally apparent that these facilities must be incorporated into the overall construction plans for the project as a whole. One of us (F.E.G.) was assigned to the project in 1938 as Resident Sanitary Engineer, and began the basic studies and the development of a program embracing the more permanent approaches to malaria control. At about the same time and in cooperation with the Health and Safety Department, planning elements of the Authority began engineering studies covering areas offering possibilities for the use of diking and dewatering in eliminating certain of the largest flood-plain problem areas. A preliminary report of these diking and dewatering studies, including an estimate of cost, was completed early in 1941. From these data and its own studies, the staff of the Health and Safety Department prepared a report to Management proposing a definite program embracing the more permanent methods of preventing mosquito production including diking and de-

watering, deepening and filling, restriction of land use to daytime occupancy, marginal drainage, and house mosquito-proofing in limited areas where this method seemed indicated. Each measure as finally selected for recommendation was fitted to the peculiarities of each type of shoreline as determined by field studies and was, in the judgment of the staff, after consideration of all possible alternatives, the most logical and economic solution. Figure II shows the

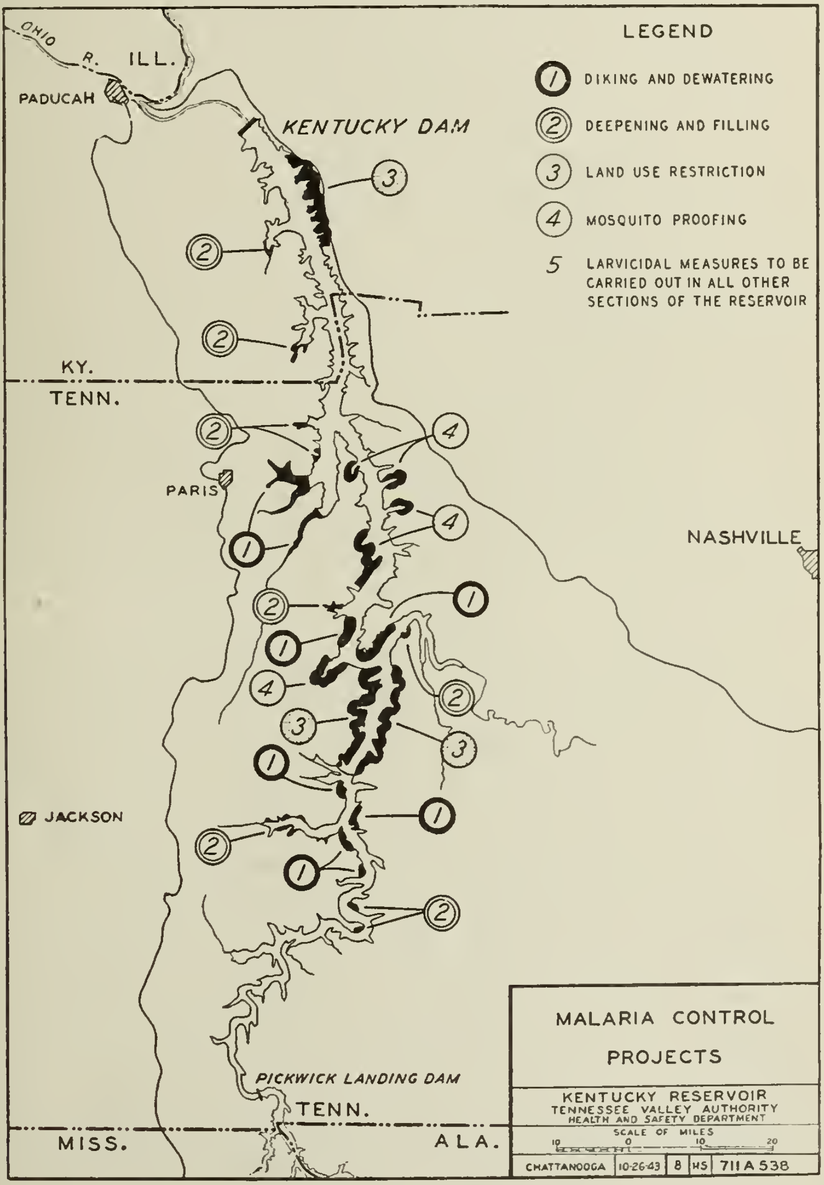

Fig. II—*The Type and Distribution of Permanent Works for the Control of Anophelines on Kentucky Reservoir.*

distribution of the several measures finally agreed upon.

The plan as a whole was then submitted to the Authority's Board of Malaria Consultants, the health departments of the states affected, two special engineering consultants, and finally on June 6, 1941, to our Board of Directors. The general approach and recommendations were approved in principle, subject to necessary evaluation of individual projects after the development of more detailed engineering plans. Thus the malaria control facilities were incorporated in the construction program for the project as a whole, and construction is now either in progress or completed on all improvements except the filling and deepening projects.

The criteria influencing the selection of various methods of control for application to the diverse problems of individual parts of the reservoir are worth consideration. The economy of each potential solution, particularly those involving capital investments and maintenance costs, were weighed against expected benefits in order that the measure finally decided upon might be realistic and in accord with sound business principles. Diking and dewatering seemed especially indicated for the largest of the flat areas with small drainage runoff and where advantage might be taken of the usual silt bank of the river in constructing the enclosing dike. In one instance it was possible to bypass water from a large portion of the drainage area through a diversion canal. Pumps with capacity to dewater the diked areas after any expected rainfall before a brood of mosquitoes can mature are being installed, and although flooded during the winter, the land will retain considerable agricultural potential.

From a maintenance standpoint, the combination of deepening and filling shallow areas is ideal. Mosquito breeding areas are eliminated and there is practically no maintenance cost. Moreover the capital costs of filling are reduced by combination with deepening operations. Except for some deep-rooted aquatic plants, for example, lotus, which it is anticipated can be controlled without serious difficulty, the marginal growth and mosquito problem area of our run-of-the-river reservoirs has been found to be limited to a zone three feet in depth. Consequently, if in a particular situation the lower half of this zone can be borrowed to fill the upper half, the whole mosquito problem can be eliminated by moving only 25 percent of the yardage required for either cut or fill alone. But despite this economy in construction, the capital cost usually exceeded that for diking and dewatering in the larger areas so that it was necessary to limit filling to the smaller areas or those where diking and dewatering would not be applicable, as for instance an excessively large drainage area where runoff could not be diverted.

Restriction of land use to daytime occupancy of the one-mile zone bordering a reservoir is certainly an effective and permanent approach to the prevention of malaria transmission. It permits the normal use of the land in every respect except for residence or other occupancy between sunset and sunrise during the malaria mosquito season. The measure is, of course, based upon the established facts that *A. quadrimaculatus* is normally active only at night and has an effective flight range of approximately one mile. Thus, in areas where this method of control is applicable, some of the capital investment and the annual cost of applying mosquito control measures can be averted and, furthermore, the margin of the lake may be utilized to the fullest in promoting and developing wildlife. Use of the measure appears particularly indicated where a serious mosquito problem, which cannot be effectively and economically handled by other means, exists as, for example, where the surrounding land has low value and a sparse population. Such conditions were encountered in a considerable section of the central part of the Kentucky Reservoir bordering both sides of the river. A detailed study developed the economy of land use restriction, and the final plan which was adopted and which is now being put into effect called for purchase of easements providing only that the land must be vacated at night. Fee ownership does not change.

Some limited use of house mosquito-proofing is anticipated as a temporary or secondary measure until more permanent solutions can be found, for a part of the problem must await filling of the pool before its definition can be completed.

It is important to note that the plans with respect to malaria control were developed through coordination and assistance from many other elements of the Authority's organization including Management, Project Planning, Maps and Surveys, Agricultural Relations, Forestry Relations, the Design groups, Construction and Maintenance, and Regional Studies. Through coordination of malaria control plans with the overall plan for the reservoir, it was possible to effect material savings in the capital investment essential for permanent shoreline improvement. Typical of this was a substantial economy in highway and railroad relocation fills resulting from the fact that lower cost construction was possible behind the levees than would have been permissible under conditions of full exposure to wind and wave action. Moreover, dewatering an area removes the need for clearance of timber which in turn provides additional protection of the fills and reduces the outlay for capital expense.

The preliminary report proposing the permanent shoreline improvement program included detailed estimates of cost covering the

conventional approach to control through use of larvicides and shoreline maintenance as compared to the combined program including diking and dewatering, filling, land use restriction, mosquito-proofing, and limited larvicidal operations with shoreline maintenance. The following summary of comparative costs—taken from the report—well illustrates the economy of the combined program. The increase in effectiveness needs no illustration.

Complete Larvicidal and Shoreline Maintenance Program

	Net Investment	*Annual Cost*
1. Larvicides, entire reservoir	$ 122,780	$ 218,685
2. Growth Removal, all flats		68,300
3. Drainage Maintenance Zone, normal fluctuation and flood surcharge zone		50,000
Total	$ 122,780	$ 336,985
Interest		– 3,685
Annual out-of-pocket cost		$ 333,300

Suggested Combined Program Including Diking, Dewatering, Filling, Land Use Restriction, Mosquito-Proofing, Limited Larvicidal Operations, and Shoreline Maintenance

	Net Investment	*Annual Cost*
1. Larvicides, all parts of reservoir not handled by other measures	$ 60,090	$ 59,100
2. Growth Removal, mosquito-proofing areas and areas where larvicides are applied		22,260
3. Drainage Maintenance, fluctuation and flood surcharge zones		42,000
4. Diking, ten areas	–43,950	40,860
5. Filling, 3400 acres totaling 2,000,000 cubic yards *	700,000	21,000
6. Land Use Restriction	112,885	3,385
7. Mosquito-Proofing	13,100	2,240
Total Cost	$ 842,125	$ 190,845
Interest (3% Investment)		– 25,265
Annual out-of-pocket cost		$ 165,580

*Methods revised and costs reduced by deepening and filling in lieu of complete filling.

The low net cost for diking and dewatering is due principally to a credit of $1,203,350 being taken for saving in clearing, highway and railroad relocation costs. It is readily apparent from the estimates that the remainder of the capital investment, ($842,125 less $62,690) $779,435, will be returned in five years, by an annual saving in maintenance costs amounting to $167,720.

Summary

The program embracing the more permanent approaches to malaria control in the Kentucky Reservoir will cover some 14,000 acres or 70% of the total 20,000 acres of potential marginal mosquito breeding surface and include almost the whole area where transmission of malaria is a serious threat. The remaining 6,000 acres is spread along the steeper and exposed shoreline where the usual antilarval operations should prove effective.

The net capital investment, after taking credit for economies in other work such as railroad and highway fills and reservoir preparation, is approximately $842,000, which on a basis of our estimates provides for an annual saving of some $168,000 or 50% of the total amount that would have been required by the conventional program of larvicidal control with shoreline maintenance. Of controlling significance, however, is the fact that the permanent shoreline improvement program will provide a very effective mosquito control which would not have been possible under the conventional antilarval program.

It is evident that the combined program of control measures can be justified by economies in annual costs alone. It is also quite probable that, under the program as it is being developed, there will be a gradual reduction in annual maintenance cost. With the usual program of larvicidal operations and shoreline maintenance, the cost would be apt to increase as aquatic plants spread through flat areas of the reservoir.

Conclusion

It is our belief that, under present plans for the Kentucky Reservoir, ample protection against the hazards of malaria will be provided within reasonable economic limits by the use of detailed technical information and the application of sound business principles. It is our purpose to extend these methods of permanent shoreline improvement to other reservoirs in which conventional methods have failed to yield the full possibilities of control both as to effectiveness and economy.

SELECTION OF ANTI-MOSQUITO METHODS TO FIT SPECIFIC MALARIA CONTROL PROGRAMS

By Sanitary Engineer (R) Nelson H. Rector

Office of Malaria Control in War Areas
U. S. Public Health Service

Before any efficient malaria control program can be undertaken it is necessary to conduct certain preliminary investigations to determine the relative importance of the disease; the location of the foci; the habits of the principal vectors; whether control is feasible; and last, to select the control methods most applicable to the existing conditions.

It is essential that the malariologist study the problem carefully and outline the areas where the need is most acute, since nearly all authorities on malaria control agree that this disease never occurs uniformly over a given area. If time permits, spot maps of mortality data and results of blood surveys should be prepared as they will indicate the areas where malaria is most prevalent and severe.

Entomological data is also indispensable. In the past, field workers have come to grief by formulating control programs based on either insufficient entomological data or by not utilizing that available. A classical example is where the indiscriminate clearing of a swamp eliminated the breeding of a relatively harmless mosquito, but thereby created conditions favorable for the propagation of a very dangerous malaria vector. It is certain that the proper use of entomological data regarding flight range, habits, length of life, etc., are essential knowledge which if properly employed, will result in decreased costs and increased efficiency of the program.

It would be obviously very unwise to attempt any work in a new location without determining the main vectors and everything known about their habits. This study should include the type of water preferred; whether it breeds more prolifically in shade or sunshine; if an increase in alkalinity tends to decrease breeding, or whether or not it breeds in running streams or still water. A study should also be made to determine the date of emergence of the principal vector in any particular region in order to time the control operations properly. In some countries it has been found that some *Anopheles* prefer animals to man and this data has been of great value in planning control programs.

After it has been decided that the disease is of economic im-

portance, and studies made of the mosquitoes concerned, the malaria worker must carefully consider the different types of methods that may be used in order to select those that will give the best results. I say "those" because it is my firm conviction that generally speaking, it is much better to use a combination of methods rather than to place full reliance on any one.

As stated previously, there are many factors that influence the methods to be used. It would obviously be unwise to recommend the same measure in parts of the world where the incidence of malaria is very high and where people live in grass huts, as in places in the United States where the incidence is low and where the residences are well screened, if not completely mosquito proofed.

The following questions are among those that must be answered before any method or methods can be selected:

1. Is the program a part of a long range program for the eradication of the disease, or is it designed to control mosquitoes in the shortest possible time during an emergency?

The answer to this question determines whether the construction of inverts, the laying of tile and the filling of ponds, or temporary measures such as the distribution of larvicides to control aquatic stages are to be the main reliance.

2. Is the incidence of malaria high and the living conditions poor, or is the rate low, the general living conditions good, and the anopheline breeding areas extensive?

The answer to this question determines whether or not it is better to reduce transmission by the destruction of adult mosquitoes in native huts, or if the main dependence will be placed in the mosquito proofing of residences.

3. Does the mosquito remain principally in residences, or outbuildings, and does it feed principally on humans or animals?

The knowledge that the *Anopheles gambia* rested primarily in residences was of great value to the officials who planned the eradication program in Brazil.

The specific anti-mosquito methods generally employed are:

1. Mosquito proofing of houses.
2. The application of larvicides to destroy the aquatic stages.
3. The permanent elimination of breeding places by draining or filling.
4. Naturalistic methods of control.
5. The spray killing of mosquitoes in dwellings and outbuildings.
6. Community education.

The use of the above mentioned methods are described in the following paragraphs:

1. Mosquito proofing of houses: I prefer to use the term "mosquito proofing" rather than screening as the object of this type of work is to make the entrance of flies and mosquitoes difficult or impossible. In many rural areas in the United States, the mosquito proofing of houses constitutes the most practical malaria control method due to the fact that the drainage would be too costly and the results do not justify its cost. It is a method being used more extensively on impounded water projects where other methods prove impracticable or ineffective.

2. Application of larvicides: The best investigators agree that the most vulnerable stage of the life of the mosquito is the aquatic or larval stage. There are those who point out that this method has a very limited use due to its temporary nature, and to the fact that it must be applied recurrently year after year. Even granting these disadvantages, and we must, it is my opinion that it will remain one of the main stays for use on emergency programs, and for the control of mosquitoes in urban areas.

In planning work for the Malaria Control in War Areas program (since it is of an emergency nature), major dependence has been placed on the use of larvicides. The larvicides used most widely on the MCWA projects are paris green mixed with dust, lime, or soapstone, or a fuel oil designated by industry as No. 2 Diesel oil. The use of pyrethrum as a larvicide has not been encouraged as it has been deemed wise to conserve this critical material, for use as an insecticide in sections where control by drainage or other larvicides is impractical. Some preliminary work has indicated that DDT and oil emulsifiers may shortly find a place in larviciding procedures.

Paris green is applied by hand; by a hand duster; by power equipment mounted on a boat or a four-wheel drive truck; or by airplanes. The oil is applied by means of knapsack sprayers or by power equipment. Small water-oil units mounted on boats have been used successfully in areas covered with heavy mats of algae or floatage.

3. Drainage: Drainage is probably accepted by most authorities on malaria control as a method having met most widespread application. It is certain that after the war a tremendous amount of so-called permanent drainage consisting of the construction of inverts (masonry, monolithic or precast), the laying of tile, and the elimination of ponds by filling, will be carried on in urban and semi-urban areas. It is my opinion that we have enough knowledge to eliminate *Anopheles quadrimaculatus* breeding in most of the urban and sub-

urban areas in the Southern United States by utilizing these more permanent methods. It should, however, be borne in mind that where labor is plentiful and cheap, it may be more practical to utilize open earth ditches on malaria control programs than to construct inverts.

On the MCWA program, drainage has been considered a method of secondary importance. On the termination of larvicidal work, most of the labor is utilized for drainage. These drainage projects are designed to eliminate breeding areas where larviciding is unsuccessful or where the cost of the drainage does not exceed the cost of larviciding an area for several years. It is believed that this well planned drainage program will materially increase the efficiency and decrease the cost of larvicidal work in subsequent years.

Where ground conditions are suitable, dynamite may be the cheapest method for the installation of a ditch. This method is of particular value for constructing outlet ditches which follow natural sloughs or bayous, where the bottom is soft, mucky and full of roots and stumps. This work can be done very quickly, at a small cost and with a minimum amount of labor, which is especially significant on account of the manpower shortage. In many instances the next best method would have cost several times the amount spent in executing the work with dynamite.

In the event the marsh or swamp is fed by seepage, a deep narrow contour ditch located just above the toe of the hill should be utilized to intercept and collect the seepage flow. If possible, tile or French drains consisting of poles set in gravel, broken stone, brickbats, or other similar material should be used to carry the water underground in order to make the drainage more efficient and permanent.

A few cities have been able to eliminate *Anopheles quadrimaculatus* breeding areas by filling them with waste material and at the same time have reduced their hauling costs for the disposal of refuse.

4. Naturalistic methods: The use of naturalistic methods where indicated in mosquito control have long been advocated by malariologists, and in some instances remarkable results have been reported. Dr. L. W. Hackett,[1] for instance, states that "We may expect that as time goes on, biological restriction of mosquito breeding will play an increasingly important role in the reduction of the cost of malaria control."

In many parts of the world it has been possible to eliminate the breeding of dangerous malaria transmitting mosquitoes by altering the composition of the water in which it breeds. A notable example was a project located at Durazzo, Albania, planned and executed by

Hackett[1]. Here the salt content of a slough which was breeding *Anopheles sacharovi* (*elutus*) prolifically was increased to a point which eliminated all breeding by connecting the slough with the Adriatic Sea.

In this country the incidence of malaria around rice fields has been relatively low; however, in some foreign countries such has not been the case. In Portugal, Dr. Rolla B. Hill,[2] by using intermittent irrigation, was not only able to reduce the malaria incidence through a reduction of *Anopheles* mosquitoes but was able to increase both the quality and quantity of the rice. Mr. Fred W. Knipe and Dr. Paul F. Russell[3] secured similar results on rice fields in India.

Probably the most common method of this type is the use of small top water minnows, *Gambusia affinis,* on mosquito control. These small fish are native to the south and it is certain that they have assisted in malaria control. They have been transplanted into other latitudes in this country, with good results, and also in other parts of the world, notably in the region of Istria in Italy.

Water level fluctuation to control anopheline breeding has been used extensively on impoundments, and is generally accepted as one of the most important methods for effecting control on artifical lakes and ponds.

It is confidently believed that biological control will play a much larger role in future malaria control programs.

5. Destruction of adult mosquitoes: The use of insecticides is meeting with much favor on malaria control programs. Of historical interest was the work of Mr. J. A. LePrince[4] in Panama. He demonstrated that by catching engorged mosquitoes at regular intervals in camps located near very extensive anopheline breeding areas, it was possible to control malaria by this method alone. His records show that the malaria rate at a camp in which the program was inaugurated was one-fortieth of the rate in a similar camp where no control was practiced.

The work of Russell and Knipe[5] in India is familiar to all. By spraying the native huts with insecticides (pyrethrum) once a week, the malaria rate in these villages was markedly reduced in three years. Later, Knipe[6] reported that in one particular village the parasite rate decreased from 80% to 0 in two years. It is certain that this type of control will be more widely used in the future, particularly in areas where control by drainage or larvicides is impracticable, and where houses cannot be mosquito proofed at a reasonable cost. Since the *gambiae* mosquito rests principally in human residences, it is possible that the use of insecticides also played a large part in the eradication of *gambiae* in Brazil.

The use of insecticides in the United States has greatly increased in recent years. In the State of Florida, for instance, Knipe[6] found that the sales of household sprays by one of the major companies, increased from 4,000 gallons in 1932 to 75,000 gallons in 1943. In a recent discussion with Dr. John E. Elmendorf[7], he informed me that it is his belief that perhaps the widespread use of insecticide sprays, has been one of the major factors in reducing the malaria incidence in the United States in the last twenty years.

The use of interior aerosol sprays offers promise of becoming a useful means of controlling explosive epidemics, or for eliminating small endemic malarial foci in the United States, in sections where it would be impractical to eliminate breeding areas by drainage or filling, or where it might be impractical or even impossible to mosquito proof the dwellings.

6. Community education: Community education is an important part of any malaria control program. Dr. Mark F. Boyd[8] stated that "No control program can be considered as adequate that does not make provision for teaching the fundamental facts of malaria transmission to the people concerned. In no other way can willing cooperation be secured."

It is our firm conviction that well trained people, by using all known facts about the main mosquito vector, and by utilizing a combination of methods most likely to break the chain of transmission, will ultimately conquer this disease, classed by many eminent malariologists as the worst scourge that has afflicted mankind. May each of us do our best to make this dream come true.

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